# THE CITRUS INDUSTRY

VOLUME II

PRODUCTION OF THE CROP

HERBERT JOHN WEBBER
1865–1946

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## VOLUME II

## PRODUCTION OF THE CROP


*Edited by*

LEON DEXTER BATCHELOR

Professor of Horticulture and Director, Citrus Experiment Station, University of California

*and*

HERBERT JOHN WEBBER

Professor Emeritus of Subtropical Horticulture, Citrus Experiment Station, University of California; Formerly Director of the Citrus Experiment Station, and Onetime Director of the California Agricultural Experiment Station

WITH THE COLLABORATION OF

ALFRED M. BOYCE
HOWARD S. FAWCETT
WAYNE E. HARMAN
ROBERT W. HODGSON
MARTIN P. HUBERTY
LEO S. KLOTZ
RALPH G. LARUE
EDWIN R. PARKER
MARVIN B. ROUNDS
WARREN R. SCHOONOVER
HARRY S. SMITH
TRACY I. STORER
HENRY J. WILDER
FLOYD D. YOUNG


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# AUTHORS OF CHAPTERS

LEON DEXTER BATCHELOR, Ph.D.

Professor of Horticulture and Director, Citrus Experiment Station, University of California, Riverside, California

ALFRED MULLIKIN BOYCE, Ph.D.

Professor of Entomology, University of California, and Entomologist in the Citrus Experiment Station, Riverside, California

HOWARD SAMUEL FAWCETT, Ph.D.

Professor of Plant Pathology, Emeritus, and Plant Pathologist, Emeritus, in the Citrus Experiment Station, Riverside, California

WAYNE E. HARMAN

Meteorologist, Fruit-Frost Service, United States Weather Bureau, Los Altos, California

ROBERT WILLARD HODGSON, M.S.

Professor of Subtropical Horticulture, Subtropical Horticulturist in the Experiment Station, and Assistant Dean of the College of Agriculture, University of California, Los Angeles, California

MARTIN RICHARD HUBERTY, Engineer

Professor of Irrigation and Irrigation Engineer in the Experiment Station, University of California, Los Angeles, California

LEO JOSEPH KLOTZ, Ph.D.

Professor of Plant Pathology, University of California, and Plant Pathologist in the Citrus Experiment Station, Riverside, California

RALPH GARRETT LARUE, B.S.

Associate Agriculturist, University of California, Assistant Farm Advisor of San Bernardino County, Agricultural Extension Service, San Bernardino, California

EDWIN ROBERT PARKER, Ph.D.

Horticulturist in the University of California Citrus Experiment Station, Riverside, California

MARVIN BIRD ROUNDS

Formerly Associate in the University of California Citrus Experiment Station, Riverside, California

WARREN RIPPEY SCHOONOVER, M.S.

Agriculturist, University of California Agricultural Extension Service, Berkeley, California

HARRY SCOTT SMITH, A.M.

Professor of Entomology, University of California, and Entomologist in the Citrus Experiment Station, Riverside, California

TRACY IRWIN STORER, Ph.D.

Professor of Zoölogy, University of California, and Zoölogist in the Experiment Station, Davis, California

HERBERT JOHN WEBBER, Ph.D., D.Agr., LL.D., 1865–1946*

Formerly Professor of Subtropical Horticulture, Emeritus, University of California, and Director of the Citrus Experiment Station, Riverside, California, and onetime Director of the California Agricultural Experiment Station

HENRY JASON WILDER, A.B.

Specialist in Agricultural Extension, Emeritus, University of California, San Bernardino, California

FLOYD DILLON YOUNG

Principal Meteorologist, United States Weather Bureau, Pomona, California

* By the death of Herbert John Webber on January 18, 1946, horticulturists throughout the world lost a beloved and respected leader whose scientific imagination, enthusiasm, and resourcefulness were of inestimable value to the advancement of science. His vision and persistent effort made the publication of this book possible. Fortunately he lived to participate in the editing of most of the chapters in this volume which may serve as a fitting memorial to such a long and useful life.—L. D. B.

# PREFACE

EACH VOLUME of *The Citrus Industry* is complete in itself, and this fact necessitates the restatement in each volume of the general plan of the work. The first volume, *History, Botany, and Breeding,* was issued in 1943 (University of California Press, Berkeley and Los Angeles, xx + 1028 pages, 233 figures). The present volume, *Production of the Crop,* covers all the ordinary orchard practices employed in producing the crop: nursery methods, choice and use of rootstocks, planting, cultivation, fertilization, irrigation, pruning, protection against frost, treatment of diseases, pest control, and related subjects. The third volume, *Harvesting, Marketing, and Utilization of the Crop,* is in course of preparation; the date of issue, however, cannot yet be announced.

As was stated in the Preface to the first volume, "the treatise is designed to present a comprehensive view of all phases of the great citrus industry, as a source of information and inspiration for growers, students, and investigators. Thus a special attempt has been made to present the material plainly, yet in a thoroughly scientific way, so that it can, in general, be understood by intelligent growers." The editors, however, have considered it fundamental that the scientific principles on which the various practices are founded should be explained. Some of the explanations in this volume may be too technical to be understood thoroughly except by specialists.

Here, as in Volume I, the different chapters are prepared by authors chosen because they have special knowledge of the subjects treated and have investigated them intensively. There is naturally some overlapping of the different subjects, and—as occurs in all fields of science—some of the phenomena presented may be subject to different interpretations. The editors have attempted, so far as seemed desirable, to unify the statements; but each author, as an investigator, is entitled to his own opinion, and thus some slightly conflicting statements—of no more than minor importance, however—may be found in different chapters. Each author is responsible for the material presented in his own chapter.

In this volume, as in Volume I, the plan has been to present the matter as applicable anywhere in the citrus-growing world. Since the text is prepared in California by California investigators, it is inevitable that emphasis is placed on California practices; but this circumstance may render the treatment even more valuable to producers and specialists in other countries who are already familiar with the methods employed in their own regions.

Two chapters in this volume deal with rootstocks. The first of these, chapter ii, discusses the rootstocks commonly used and their reactions. It is a general summary of our understanding up to the present, based, in large part, on "trial and error" methods. The relation of rootstocks to the spread or prevention of various virus and fungus diseases has stimulated, in all citrus-producing countries, an intense interest in rootstock problems, and thus it has seemed to the editors that this volume should contain a rather full statement of the results obtained in the rootstock experiments of the California

Citrus Experiment Station, which have been in progress for a quarter century. These are probably the most extensive and longest-continued experiments ever conducted with citrus rootstocks, and the results obtained have not been fully published. Chapter iii outlines, in the main, the results and conclusions thus far reached. Some data from them are also used in chapter ii to illustrate specific items; and there is thus some little repetition in the two chapters. There are in the data here presented (chaps. ii and iii) many seeming inconsistencies that cannot at present be entirely accounted for: different reactions under different conditions as yet little understood. Much more extensive data must be acquired before the inconsistencies can be explained.

Chapter xi, "Diseases and Their Control," by Howard S. Fawcett and Leo J. Klotz, is designed to summarize and supplement the much fuller treatment of this subject published by Dr. Fawcett in a special volume (*Citrus Diseases and Their Control*, McGraw-Hill Book Company, New York and London, 1936; 656 pp., 187 figs.). The subject of chapter xiv, on "Insects and Mites and Their Control," by A. M. Boyce, is more fully treated in a special text (Quayle, Henry J., *Insects of Citrus and Other Subtropical Fruits,* Comstock Publishing Co., Ithaca, N.Y., 1938; 583 pp., 577 figs.). We are indebted to Professor Quayle for many helpful suggestions in the preparation of chapter xiv and for the use of many of his photographs. The general form of this chapter follows much the same composition as the special text on this subject. The two books referred to thus constitute, in effect, volumes in this series on the citrus industry and should be in the libraries of all citrus growers and technicians.

The editors wish to express to the authors of chapters in this volume their heartfelt thanks for the kind and efficient coöperation they have given to the task of preparing and editing their chapters; without such assistance the work could not have been satisfactorily completed. It is also fitting that we should acknowledge the generous support given to this project by the authorities of the University of California, under whose general direction the work of the editors and most of the authors of chapters is conducted. We wish especially to thank Dr. Claude B. Hutchison, Vice-President of the University and Dean of the College of Agriculture, and Mr. Samuel T. Farquhar, Manager of the University of California Press, who have at all times given encouragement to the editors in their work.

It is a special pleasure and privilege, also, to express to our colleagues, the various members of the staff of the Citrus Experiment Station, our appreciation for their continued support and assistance. Almost every member of the staff has rendered some assistance in the preparation of this work, either by supplying ideas, material, or photographs, or by reading manuscript or proof.

The drawings and photographs used throughout the text are to be credited to the authors of the chapters in which they occur, unless other credit is specifically given. A number of colored illustrations used in chapter vii, "Principles and Methods of Fertilization," were originally made by the Florida Agricultural Experiment Station. Through the kind coöperation of the National Fertilizer Association, plates were lent us for reproducing these

colored illustrations. The editors are also indebted to Dr. A. F. Camp, Director of the Florida Citrus Experiment Station, for many valuable suggestions. The drawings illustrating chapter i, "Nursery Methods," were made by Mrs. Lucene Hardin Webber (Mrs. H. J. Webber, deceased).

The literature citations given at the end of each chapter in this volume have all been checked and edited by Miss Margaret Buvens, Librarian of the California Citrus Experiment Station. The manuscripts of chapters have been read and edited by Mrs. Frances Hayes, Publications Editor, and by Mrs. Helen Freeland, Administrative Assistant, both of the California Citrus Experiment Station. Mrs. Freeland has also assisted greatly in the mechanical details of preparing the manuscripts. Lastly, much of such merit as the publication may be found to deserve is due to the able assistance of Mr. Harold A. Small, Editor of the University of California Press, in guiding the work into print. To all these and to many others not specially mentioned who have supplied data, or otherwise aided in the work, the editors wish to express their thanks.

L. D. B.
H. J. W.

Riverside, California
September 1, 1948

# CONTENTS

## Chapter I

# NURSERY METHODS

BY

HERBERT JOHN WEBBER

The methods[1] used in the propagation of citrus trees do not differ materially from those employed with other fruit trees. The principles are the same for all plants; but experience has shown that for citrus some methods are preferable to others. The nursery methods now practiced in this industry are about the same the world over.

Fifty years ago, the first and most difficult decision to make was whether to use seedlings or budded trees (Webber, 1897, p. 471). Fortunately, this matter is no longer in question. It is now well understood in all citrus-growing regions that the building of a successful commercial citrus industry must rest on the propagation and planting of only selected, disease-free varieties known to be suited to the region and to produce fruit of known good quality. Since the best commercial varieties do not reproduce true by seed, they must be propagated by budding or grafting, by cuttings, or the like.

In general, the propagation of citrus varieties is accomplished by budding into seedlings of species known to give good results when used as rootstocks. It is highly important to use rootstocks known to be adapted to the variety to be grown and to the region and soil on which the trees are to be planted (see chaps. ii and iii, below).

Budding is by far the most generally used method of propagation. Grafting apparently gives just as good results, but it is more difficult and slower. Sometimes propagation is effected by means of layers, marcotts, and cuttings; but these methods are at present little used in the principal citrus regions, though they apparently have a definite place in the industry in some sections.

The propagation and growing of trees in a nursery is highly specialized, intensive work, and only those who give careful attention to all phases of the subject are likely to obtain satisfactory results.

## SEEDS FOR ROOTSTOCKS

### KIND OF SEED TO BE USED

The seeds most commonly used for citrus rootstocks in the United States are those of the sweet orange, sour orange, grapefruit, shaddock, Rough lemon, and trifoliate orange. In other citrus-growing countries different species or

[1] The methods outlined in this chapter are those tested or studied by the writer and commonly used in California and Florida. Many variations of these methods and other methods are in use, but the ones described here are standard and may serve as helpful guides. Important literature on this subject not specially referred to in the text includes the following: Brown (1924); Camp (1938, 1945); Hatton *et al.* (1932); Henricksen (1904); Nagai and Takahashi (1928); Provan (1933); Rolfs (1913); Rolfs and Rolfs (1931); Tanaka and Tanaka (1932); Turner (1923); and Wester (1916). For complete data on citations see "Literature Cited" at the end of the chapter.

varieties are sometimes used, as, for instance, the sweet lime in Palestine, the yuzu orange in Japan, and the Calamondin and mandarin in the Philippine Islands. The stock to be used for any particular variety in a given place must be carefully chosen in accordance with what is known to be good practice in that place (see chaps. ii and iii, below). A stock successful with a certain variety in one place may not be satisfactory in another.

In the determination of the stock to be used, emphasis has heretofore been placed on the species; it was thought to be sufficient merely to decide between sour orange, sweet orange, or grapefruit, and the like. It is now generally recognized that the seedlings produced by different varieties of any of these species will themselves differ and that it is highly important that the seed for growing stocks should be taken from selected trees of the species to be used. The evidence thus far available indicates that this is very important where the sour orange, sweet orange, or grapefruit is used; it is less important where varieties such as Rough lemon, Palestine sweet lime, or Sampson tangelo are to be employed, since they are known to reproduce remarkably true to type through seed propagation.

Until special rootstock varieties are available for propagation, especially to produce seed for nursery purposes, it will be necessary to take the seed from selected healthy trees of the species chosen. In California, good trees of rootstock types known to be free from the virus of scaly bark are being chosen and registered by state agencies as approved sources for rootstock seeds.

The reactions of various stocks on different varieties of citrus and the methods of stock selection are fully discussed in the next chapter.

## SOURCE OF SEED

The seed for use in each country or each citrus region is generally obtained from local trees. Citrus seed very soon loses its vitality if dried; it is thus usually impractical to obtain seed in bulk from any great distance. Most of the sour orange seed that for many years has been extensively used in California for nursery purposes is produced in Florida and Cuba[1]—probably a unique situation; at any rate, the writer does not know that the citrus industry elsewhere depends in any marked degree on importations of seed for its nurseries. Most of the Rough lemon seed for nursery use in California is imported from Florida, but only small quantities are used.

In almost all citrus-growing countries there are trees enough of the kinds desired for stocks to assure a local supply of seed from known good trees. Nurserymen should propagate and grow a sufficient number of trees of the best stock varieties to produce, for themselves, a supply of seed of known varieties and of known freedom from disease. They will thus be able to demonstrate to growers the type of stocks they are using, a matter likely to become increasingly important.

Whatever species or variety may be used for stock, the seeds should always be taken from good, fully matured fruits grown on vigorous, healthy trees.

[1] To import citrus seed into California, permission and directions must first be obtained from the State Department of Agriculture.

Very few diseases are known to be transmitted through the seed or on the seed, except to a very limited degree; but in any case, seeds from healthy trees are safer to use and are generally more vigorous than those from unhealthy or inferior trees. The seeds from frost-injured fruits are evidently as good to use as those from unfrosted fruits. This was found to be true with frozen fruit in Florida after the very severe freeze of 1894–95.

### EXTRACTION OF SEED, AND AMOUNT NECESSARY

The most common method of extracting the seed is to separate the fruits into halves by making a shallow cut through the skin and twisting them apart. The contents are then squeezed into a large sieve having a mesh coarse enough to let the juice and pulp be washed through. Another common method is to place the fruits in barrels, cover them with water, and permit them to stand until the soaking and rotting softens the peel so that the whole fruits can be thrown into a large sieve and the seeds washed clean of pulp. Some nurserymen have devised threshing machines that tear the fruit into shreds, wash the seeds out, and separate them from the pulp; but such machines are not regularly manufactured.

It is important to provide a larger number of seeds for planting than the number of seedlings desired. In the majority of citrus species and varieties the seeds are polyembryonic, and frequently from two to three seedlings develop from one seed. The number of seedlings obtained may, indeed, exceed the number of seeds planted; but this rarely occurs. Usually, a stand of one-half to three-fourths as many seedlings as seeds planted may be considered a fair return. The small, slow-growing seedlings should be discarded, a process which further reduces the number. It is thus safe to say that at least twice as many seeds should be planted as the number of seedlings desired.

As a guide to the number of fruits required to supply the planting seed desired, one fairly accurate method is to make an estimate of the average number of seeds per fruit by counting the seeds in from twenty-five to fifty fruits of the stock variety. The number of seeds produced by the same variety may vary from one year to another, and accurate methods of calculation are therefore desirable.

Seeds of different species of citrus also vary greatly in number per fruit and in size (see Vol. I, fig. 191, p. 799), and the estimate of seed number for one species has no relation to the numbers to be expected in other species or in different varieties of such species.

Citrus seed for nursery use, especially of the sour orange, is frequently harvested in quantity and sold in bulk by the pound or bushel. Estimates of the number of seeds for such units of measure are so variable as to be of little value. Seed supplied in large quantities in bulk is almost invariably taken from unselected trees, and the use of such seed of unknown heritage for rootstocks should be discouraged.

Citrus seeds of the same variety vary greatly in size, even in the same fruit, and there are many rudiments with undeveloped embryos. Some growers have taken the trouble to separate and discard the small seeds; but the rudimentary

seeds in which the embryos are not developed are light and most of them can be floated out when the seeds are in water and being washed clean of pulp. This is the only separation that need be made. A separation based on size or weight is of no value with citrus seeds, for a small seed may have one large embryo whereas a much larger and heavier seed may have several embryos none of which is as large as the one embryo in the smaller seed.

#### STORAGE OF CITRUS SEED

If citrus seed is allowed to dry, it soon loses its vitality. If the seed is to be kept for some time, say several months, it should be surface-dried quickly after being thoroughly washed, and should then be mixed with equal parts of ground charcoal, packed in a tight wooden box or tin container, and kept in a damp, cool place, preferably between 38° and 55° F.

Sweet orange seed and grapefruit seed are somewhat more quickly injured by drying than the seed of the sour orange or the Rough lemon; but although seeds of different species may show some difference in susceptibility to injury by drying, this difference is slight, and no citrus seed can safely be kept for long. Sometimes the seed is harvested in the early winter, stratified in clean sand (instead of ground charcoal), and kept through the winter in a cool, damp cellar. This is not a practice to be generally recommended.

## THE SEEDBED

#### LOCATION AND ARRANGEMENT

If only a few seedlings are to be grown, the seeds may be planted in boxes of convenient size, containing soil 8 to 10 inches in depth. The boxes should be put in a warm, partly shaded place, and the soil should be kept moist but not wet. If large numbers of seedlings are to be grown, special seedbeds should be prepared in comparatively warm places on good, well-drained soil. Almost any type of soil may be used, but a rather light sandy loam is to be preferred. It is desirable to use virgin soil, if that is obtainable, or soil which has not for several years been used for the growing of citrus seedlings or vegetables. If a seedbed is grown on the same land for several years in succession, the soil is likely to become so much infected with damping-off fungi as to cause serious loss. It is further desirable to select a site at some distance from other citrus plantings, in order to reduce the danger of infestation with pests.

The soil, if fairly rich, may not require fertilization, but on light soils that are deficient in plant food some fertilization should be given before planting. For this purpose commercial fertilizers, rich in nitrogen, such as are recommended for young trees and vegetables, should be used. In California an application of some soluble nitrogen carrier, such as sulfate of ammonia or nitrate of lime, is usually all that is required. About the same quantities should be used as would be applied in the fertilization of an area of equal size in a mature citrus grove.[1] The use of organic manures on seedbeds is not usually

[1] This means the application of about 2 to 4 lbs. of sulfate of ammonia or 2½ to 5 lbs. of nitrate of lime (approximately 6 to 13 oz. of actual nitrogen) to each 100 sq. ft. of soil surface.

considered safe, owing to the greater probabilities of introducing damping-off fungi. Any fertilization given before the seeds are planted should be spread and thoroughly mixed with the soil by tillage a month or more before the seeds are planted. Young seedlings are frequently burned and injured if the seeds are planted too soon after the application of the fertilizer. Land for planting should be thoroughly and deeply tilled and put in good physical condition. If too loose, it should be firmed with a light roller. It is then ready for planting.

In all citrus regions, seedlings are generally grown under some sort of shed (fig. 1), in order to provide a certain amount of protection from the full rays

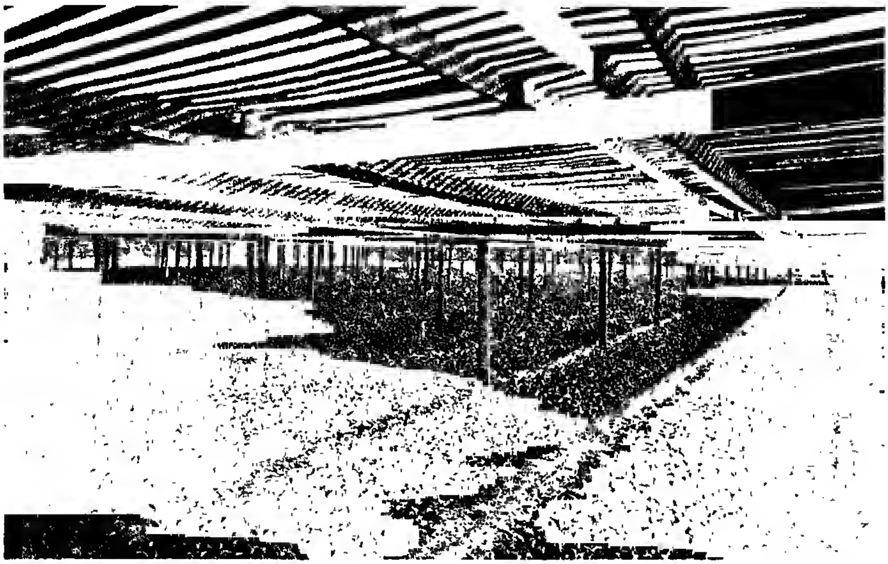

Fig. 1. Citrus seedbeds under lath shed, irrigated by sprinkling from overhead pipes. (Tetley Nurseries, Riverside, California.)

of the sun, to check the evaporation of moisture from the plants and the soil, and also to serve as a protection against injury from freezing. They make a better growth when thus protected. In California such sheds are usually covered with building lath nailed to boards in standard-sized sections, with open spaces of equal width between laths. In this way a half shade is provided. The laths are usually run north and south in order to provide a more uniform distribution of the sunlight exposure and to prevent burning of the foliage.

In Florida similar sheds are employed, but boards (1 in. by 3 in. by 16 ft.) are generally used instead of lath for the cover, the boards being placed 3 inches apart to give the half shade. Sheds covered with a thin cloth, such as cheesecloth, are also sometimes used.

It is by no means necessary, in humid countries, to place the seedbeds under shade. Some nurserymen plant part or all of their stock in the open without shade. If this is done, it is necessary to give more careful attention to the water-

ing during the early period of germination and growth, or the proportion of seedlings obtained is likely to be much lessened. Unshaded seedlings in California rarely give as good a growth as those in sheds. On the other hand, one of the most experienced nurserymen in Florida states: "The better plan is to provide ample irrigation and grow the seedlings in the open, *i.e.*, without shade, and sow the seed late enough to escape frost injury. In Florida, experience has shown that in this way excellent seedbeds may be grown on the same soil for many years, and, if careful attention is given to irrigation when the seedlings are coming through the ground, there is no danger of having the crooked stems [*i.e.*, when just coming through the soil] injured by sun and wind." (Hume, 1926, p. 166.)

There are many ways of arranging seedbeds. In all, however, care must be taken to provide for tillage, and if the beds are in a lath house the arrangement must be adapted to the type of irrigation to be used and to the spaces between the posts.

When furrow irrigation is employed, it is a common practice to plant the seeds in long beds or strips about 10 to 12 inches wide, with spaces of similar width between the beds to provide for the irrigation furrows and for tillage. Approximately every sixth bed or row is omitted to allow for a pathway to facilitate working around plants. This, with slight variations, is the common practice in California in lath-house culture. If facilities for irrigation by sprinkling are available, seedbeds 3 to 4 feet wide may be planted, with paths 12 to 18 inches wide left between them to make cultivation easier (fig. 1). Almost any arrangement of beds may be used, if satisfactory provision is made for irrigation and tillage.

If seedlings are to be grown on a very large scale in the open, they may be planted in rows or narrow beds with a 2½- to 3½-foot space between them to provide for cultivation.

### PLANTING AND GERMINATION OF SEED

The seed is usually planted in the early spring after the danger from frosts is past. In both California and Florida most of the planting is done between early March and late April, though planting may be done during any of the spring or summer months, whenever the seed is available. It is preferable to get the seed planted fairly early in order to have the benefit of the full growing season. The only exception, among the species now used as stocks, is the trifoliate orange, the seed of which is planted in October or as soon as the fruit is fully ripe.

Citrus seeds will start to germinate when the soil temperature somewhat exceeds 55° F., which is approximately the zero temperature of growth (see Vol. I, p. 58). The temperature of the soils of southern California commonly reaches this point about the first of March. If planting is too early, a warm period, which causes germination to start, may be followed by a cold period, and the seed is then likely to rot in the ground. Good germination is usually obtained when the mean daily temperatures range between 58° and 65° F., and where citrus is grown in California these temperatures are usually reached

in the middle or latter part of March or in April. Under conditions permitting the temperature to be controlled and kept uniform, optimum germination is obtained at a temperature of approximately 80° to 90° F. (see Vol. I, pp. 56–58; also Fawcett, 1929; Camp, Mowry, and Loucks, 1933).

The seed, if not freshly extracted from the fruits, is often placed in moderately warm water and allowed to soak for twenty-four hours or more before planting. Some nurserymen incubate the seed in warm, moist chambers for several days before planting, mixing the seed with an equal amount of moist sand and holding it in a moist chamber at a temperature of about 90° F. The object of these measures is twofold: first, to hasten the process of germination, and second, to prevent the development of "gooseneck" or "bench root" in the seedlings.

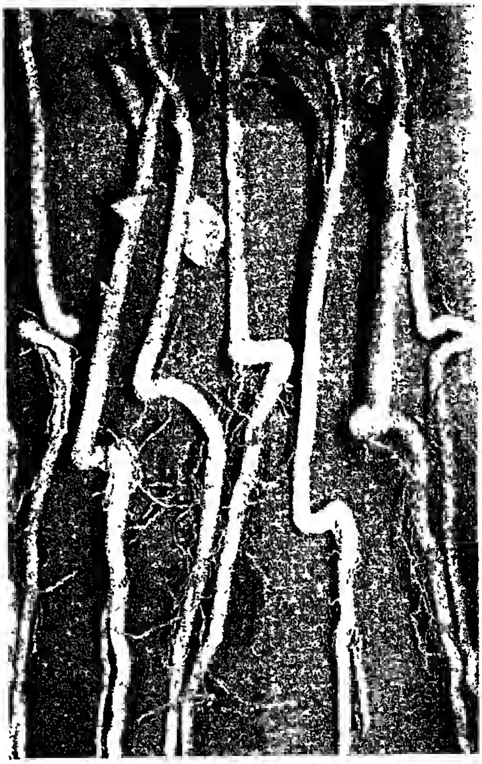

Fig. 2. Seedlings showing extreme gooseneck or bench-root condition. Such seedlings should be discarded.

Frequently, a rather large proportion of the seedlings will show a more or less S-shaped curve (gooseneck or bench root) in the young root-stem or hypocotyl (fig. 2) as they emerge from the seed, and this is thought to be injurious to the future growth of the seedling. Ralston (1915) published data indicating that this bending of the hypocotyl is caused, to an appreciable degree, by the resistance which the dry seed coats present to the emergence of the young roots. The proportion of bench-root seedlings formed was considerably reduced by soaking the dry seeds in water for 24 to 36 hours before planting, or by planting fresh seed direct from the fruit. Nasharty,[1] however, has found that the crowded nucellar embryos developed in citrus seeds frequently grow in such positions that the hypocotyl (root end) may be turned at various angles away from the micropylar end of the seed, from which the roots emerge in germination, and that the abnormal position of the embryo may cause various degrees of curvature or even complete turns to be made by the roots as they emerge. The "gooseneck" formed in the roots

[1] Ahmed H. Nasharty, of Alexandria, Egypt, a special student at the University of California, Los Angeles. Unpublished data communicated to the writer.

of such embryonic seedlings apparently could not be much influenced by the soaking and softening of the seed coats.

Experiments conducted by several nurserymen, and observed by the writer, seem to show that the "gooseneck" condition exhibited by seedlings is commonly not so abnormal as to result in permanent injury. Apparently, only very severe cases of gooseneck are to be considered as injurious (fig. 2), and seedlings showing such abnormalities should be discarded when they are dug from the seedbed.

Citrus seed is ordinarily planted by hand, the seeds being placed about 1 inch apart each way in the beds, and from ¾ inch to 1 inch deep. A method commonly followed is to spread the seed as thickly as desired on the surface of the soil in the beds and then to press them into the soil by placing a board over them and walking on it. This presses the seed down firmly in the soil in the normal position—they should lie on their sides as they naturally fall. The bed is then covered to the desired depth, about ¾ inch, with a layer of clean river sand. The ground should always be moist at the time of planting. The seed may also be sown in shallow furrows and afterward covered with ordinary soil, if sand is not available. The sand covering helps to prevent both the spread of damping-off fungi and the formation of a surface crust which might hinder the emergence of the tender young shoots. Under the most favorable conditions the young shoots may appear above the ground in two weeks, but usually a month or six weeks is required.

### CARE AND TILLAGE

The seedbed must be handled carefully if it is to be maintained in a healthy condition. It must be kept free from weeds and just moist enough to encourage growth. An overmoist condition which would encourage the development of damping-off should be avoided. The fungi producing the disease known as "damping-off" cause more damage in seedbeds than any other disease-producing agents. They are likely to be present in soils containing decaying organic matter, and to infect the young shoots at or near the surface of the soil. They spread very rapidly in the soil, under favorable conditions, and it is not uncommon to find that the plants on a sizable area have withered in a single night.

Conditions favorable to damping-off are wet soil, dense shading, humid atmosphere, and overcrowding. The control methods that can be used successfully are mainly preventive, such as irrigating at less frequent intervals and using a clean sand covering for the seeds. The sand covering will allow the surface of the soil, where infection most frequently occurs, to dry off quickly after irrigation. If an infection appears, a thorough, shallow cultivation should be given in order to dry off the surface soil, and the shade should be reduced if it is too dense. The seedlings may also be pulled up for a space of a foot or more around the diseased spot and thinned out in a circle several feet in diameter. Spraying with bordeaux mixture or treatment with Semesan is also advocated by some.

Weindling and Fawcett (1936) in experiments with *Rhizoctonia solani*, one of the most common damping-off fungi attacking citrus seedlings in Cali-

fornia, found that applications of aluminum sulfate gave a marked degree of control. The chemical was applied to the surface of the soil before seeding, at the rate of 35 grams per square foot, and raked into the top inch of the soil. By this means the loss was reduced from more than 31 per cent, as shown by untreated plots, to 1.7 per cent for the treated plots. The effect of the treatment was explained as primarily due to the action of the aluminum sulfate in increasing the acidity of the soil and thus favoring the growth of a secondary parasitic fungus, *Trichoderma*, commonly present in soils, which attacks and destroys the *Rhizoctonia* fungus.

A similar control was obtained by covering the seed to a depth of about ¾ inch with peat. Neither of these treatments has as yet been commonly used in commercial nurseries.

A type of gummosis due to the brown rot fungus sometimes causes damage in the seedbed after the seedlings have reached a height of 8 inches or more. It appears as an exudation of gum just above the ground. If the disease is found to be prevalent, the plants should be sprayed with weak bordeaux mixture (2–2–50), care being taken to cover the stems near the ground.

Reichert and Perlberger (1936) and Reichert (1938) have made extensive studies of the diseases causing injury in citrus seedbeds in Palestine. Twenty-eight different diseases were identified, and losses of from 30 to 90 per cent of the plants were recorded. The most important diseases were found to be fungus root rots caused by species of *Rhizoctonia, Sclerotinia,* and *Phytophthora,* and a physiological disorder, albinism. The best method of control for these fungus diseases was found to be: (1) the disinfection of the seed by soaking for 30 minutes in a solution of "Uspulun" or "Ceresan," strength 1:1,000; (2) germination in cold seedbeds; (3) daily airing [removal of covering shade for short period]; and (4) weekly spraying with bordeaux mixture, strength 0.5 to 1.0 per cent [2–2–50 to 4–4–50 mixture].

Albinism, or the production of white, chlorophyl-lacking seedlings, which caused an estimated loss of 30 per cent in seedbeds of sweet lemon (the Palestine sweet lime) in Palestine (Reichert and Perlberger, 1936), was eliminated by disinfecting the seeds with a solution of "Ceresan," strength 1:1,000. With sour orange seeds, a disinfection with 1:2,000 solution gave complete control.

After the seedlings reach a height of 4 or 5 inches, they are not so susceptible to attacks of damping-off and may then be irrigated rather more liberally to force the growth. Where the soils lack plant food, several light applications of fertilizer may be made during the season. Frequent shallow cultivations should be given and all weeds should be removed.

The seedlings are usually allowed to remain in the seedbed for one or two years, or until they reach a diameter of about $\frac{3}{16}$ inch to ¼ inch. In many places this will require two years, but where the soil is rich and the temperature is continuously high they will attain the required size in one year. It is poor policy to transfer seedlings to the nursery before they reach the proper size, as their care is less expensive in the seedbed. Little saving in time is made by their transfer earlier, as it is not advisable to bud them until they reach a

diameter of about 3/8 inch. Some very rapidly growing rootstocks, such as the Rough lemon, may attain the proper size earlier than seedlings of sour and sweet orange, which are slow growers. It should be said that some nurserymen bud their trees when they are much smaller and rarely or never leave the trees more than one year in the seedbed and one year in the nursery before budding.

### DIGGING AND SELECTION OF SEEDLINGS

The seedlings are dug from the seedbed just before they are transplanted to the nursery. The beds should be thoroughly irrigated several days before the digging, so that the soil will be in good condition.

The seedlings are dug from the bed by lifting them with a spade or spading fork. If they are comparatively small, the best plan is to use a spading fork to loosen the earth, after which they can be lifted out by hand. If, however, they are as large as they should be after two years in the seedbed, it may be necessary to use a sharp spade to cut the taproots about 8 to 10 inches below the surface and loosen the plants before lifting them out by hand.

As the plants are dug they should be placed in tubs, with their roots in water, for removal to the packing shed for grading and preparation. The packing shed should be well protected from drying winds and should exclude sunlight. If a moderate wind is blowing, a canvas should be thrown around the packing shed.

In the packing shed the seedlings should be examined and the good ones selected for planting in the nursery. All small, diseased, or imperfect plants should be discarded. Too much emphasis cannot be placed on the importance of rigid selection at this time. Most of the dwarfish, "off-type," variant seedlings, worthless as stocks, will be eliminated if the small seedlings are thrown out. (For full discussion see chap. ii, p. 139.) All seedlings showing any disease should also be discarded, as well as any showing severe gooseneck (bench root) or other imperfections. If this selection is properly carried out, probably a fifth to a fourth of the seedlings will be discarded at this time.

After the seedlings are graded, the tops and roots are cut to the required length. The roots are usually cut back to a length of about 8 inches, and about one-third of the top is removed. The seedlings are then packed in pails or tubs, with the roots in water, for removal to the nursery; or they are bunched and packed in boxes with damp sphagnum moss or sawdust for shipment. Everything must be done quickly, for citrus plants are easily injured by drying of the roots.

## THE NURSERY: ITS ARRANGEMENT AND CARE

### WHY PLANT IN A NURSERY?

Seedlings are usually transplanted to a special nursery in which they are grown close together until they reach the proper size for budding. They are then budded, and the buds are forced and grown into the standard nursery trees.

Growers who produce their own trees sometimes transfer the seedlings from the seedbed direct to the orchard and there do the budding at the appropriate

time. The trees may then continue their growth without the interruption of a second transplanting from the nursery to the orchard. But this means that one must walk over, cultivate, and irrigate an acre of orchard land instead of the 100 feet of a nursery row. Furthermore, the loss of a seedling in transplanting or budding is much more serious in the orchard than in a nursery row. Experience has shown that little time is saved by direct transplanting to the orchard, and the greatly increased expense and hazard resulting from this method render the use of a nursery desirable.

### SELECTION OF NURSERY SITE

The nursery should be in a warm place where the danger from frost injury is reduced to a minimum. It should preferably be on a deep, rich, fine sandy loam or loam soil, free from stones and containing clay enough to make the soil hold together and to permit "balling," if this method of transplanting is to be used. If the trees are to be balled, it is important that the nursery soil be of the same texture as the soil of the grove into which the trees are to be planted; or, if not the same texture, then lighter. If the nursery trees are to be transplanted "bare-root" to the orchard, it probably does not much matter what type of soil is used in their production. However, Nusbickel has stated: "It is my belief that stock raised in a light soil will give many more fibrous roots than that raised in a heavy soil, and that a tree which is to be transplanted 'bare root' should have the fibrous roots which a sandy or loam soil produce."[1]

If the soil is not rich enough, it may be improved by a cover crop turned under six weeks or more before the seedlings are planted, or by a dressing of well-rotted manure or commercial fertilizer turned under several weeks before the seedlings are planted. The ground should be plowed deep and should be thoroughly tilled before planting.

### PLANTING THE SEEDLINGS

In California the seedlings are transplanted to the nursery in early spring, preferably in March or April. In Florida the ordinary time of transplanting is in November or December, but the seedlings are often planted in summer, when rains occur (Hume, 1926, p. 167).

The seedlings are set in straight rows, carefully laid out from 3½ to 4 feet apart, with the plants spaced from 12 to 15 inches apart in the rows. A planting line with the proper spacing marked on it may be used to insure good results. A three-wheeled marker with blocks attached for proper spacing drawn down the line will speed up the planting.

The holes in which the seedlings are to be planted are usually made by thrusting a nursery dibble (fig. 3) or spade into the ground and pressing the soil apart so as to leave an opening of the desired depth. The root of the seedling is then placed in the opening and held erect at approximately the same height as in the seedbed while the soil is pressed firmly around it with the foot. In placing the seedling in the hole, it is highly important that the young and

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[1] F. H. Nusbickel, a well-known California nurseryman, in a letter to the editors, January 20, 1944.

flexible main root should not be pushed down with the end bent upward; it should be kept straight so that it will grow in a natural position. Some care is also necessary to make sure that the soil is pressed firmly around the base of the root as well as around its top. In arid countries irrigation should follow the planting in each row as soon as possible.

In the employment of one method of planting in California, irrigation furrows are so made as to mark the planting rows. Water is run into the furrows for a short time before planting, in order to moisten the dry and crumbly surface soil so that it will not rattle into the dibble holes. The seedlings are then planted, and the soil is firmed around them, after which the water is again run down the furrows to firm and settle the soil thoroughly around the plants. Since the water should be run in direct contact with the seedlings, it is best to plant in shallow furrows and place the seedlings slightly higher than would be done in level soil.

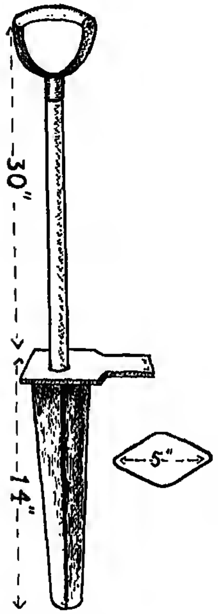


Fig. 3. Nursery dibble.

In good nursery soil that is not too sandy the planting may be done quickly by opening up a 10-inch-deep furrow with a plow having a good sharp colter. The seedlings are then held in place against the clean vertical cut face, and the earth is filled in around them. The water should follow close behind the filling-in.

In regions where irrigation is not used, planting should be done when the soil is moist, and if rain does not follow soon, the seedlings should be watered to firm the soil and give them a proper start. In most citrus-growing countries it is difficult to grow good nurseries unless facilities for irrigation are available.

## CULTIVATION, IRRIGATION, AND FERTILIZATION

The nursery must be kept thoroughly cultivated and free from weeds at all times. In arid, irrigated sections, water should be applied about every 10 to 15 days. In heavy soils less frequent irrigation may be required. In some very rich soils no fertilization is required, but fairly heavy fertilization usually improves the growth. In California the general practice is to use some form of nitrogen, such as nitrate of lime, nitrate of soda, sulfate of ammonia, or dried blood, applied at a rate to give from 200 to 300 pounds of actual nitrogen per acre. The general policy is to put this on in two equal applications, one in early spring and the other in midsummer. In Florida, complete commercial fertilizers rich in nitrogen, such as are recommended for vegetables, are commonly used, and are given in two or three applications.

Fertilizers are spread broadcast on the soil between the rows and are cultivated in, unless they are in the form of soluble materials such as nitrate of lime or sulfate of ammonia. These materials may be spread in the freshly opened irrigation furrows to be carried down by the water, which is turned on and

allowed to trickle slowly through the furrow. In California, such soluble materials are sometimes applied in the irrigation water through the use of special applicators connected to the irrigation system. Every effort should be made to keep the seedlings growing vigorously.

If the seedlings are of good size, about 1/4 inch in diameter, when transplanted to the nursery, they should reach the best size for budding by the next fall, or within about 6 months. After insertion, the buds should produce good-sized trees suitable for transplanting by the second spring following, which will be about 18 months after the buds are inserted.

The best-sized trees to bud are those that have reached a diameter of from 3/8 inch to 1/2 inch, from 4 to 8 inches above the ground.

## BUDDING THE NURSERY SEEDLINGS

### WHEN TO BUD

Budding can be done whenever the nursery seedlings reach the proper size and are in such a growing condition that the bark will slip to allow the insertion of the buds. A decade or two ago, budding was most commonly done in the early spring as soon as the bark would slip; but this is generally the rush season for all grove and nursery operations. The seedlings that are ready to bud in the early spring could have been budded the fall before, as there is little growth during the winter. Fall budding, or "dormant budding," as it is called, has thus become almost the universal practice in commercial nurseries. Two factors favor fall budding. First, the major operations may be carried out in the early fall, from September to November, when there is a slack labor period. Second, seedlings budded in the fall can be cut back in the early spring just before growth starts. All the growth of the season is thus forced into the bud, and the result is a larger season's growth than can be got from spring buds.

The principle in fall budding is to insert the buds and get them healed on just before the arrival of the winter's cold, so that they will remain dormant during the period of arrested development of the rootstock trees. Since the growth stops and the bark sets at different times, because of varying climatic conditions and variation in stock varieties used, careful attention must be given, in any locality, to the time of budding. At Riverside, California, fall budding is usually done between the 10th and 20th of October, but the period varies slightly in different seasons. Trifoliate orange seedlings frequently must be budded earlier. In the Oroville section of northern California, fall budding must usually be done ten days earlier than at Riverside. In Florida it can usually be done successfully as late as November.

### PREPARATION OF SEEDLINGS FOR BUDDING

In order that seedling development may be as large as possible, little pruning is done in the nursery. Pruning tends to retard the growth and, if severe, greatly reduces the size of the seedlings and prolongs the period necessary to hold them in the nursery before budding.

It is usually considered desirable to examine the seedlings soon after their growth is well started, for the purpose of finding and removing any vigorously

growing shoots that spring from the main trunk near the base, where the bud must later be inserted. This pruning to force the growth mainly into a single trunk up to the height of the bud insertion (6 to 10 inches) is certainly the only pruning of nursery-stock seedlings that is justified, and it should extend only to the removal of branches that threaten to divide the growth of the main trunk. Even this pruning is frequently omitted.

Shortly before the budding, then, the seedlings are pruned to a single bare trunk up to a height of 6 to 10 inches, depending upon the height of budding adopted. Severe pruning on a young tree tends to "set the bark" so that it will not slip again until new growth starts. It is therefore advisable to do the preparatory pruning two weeks or more before the budding starts; otherwise the pruning should be done at practically the same time as the budding.

Sour orange, Rough lemon, citrange, and trifoliate orange seedlings tend to grow upright, with a single trunk, and usually require but little pruning. Sweet orange, shaddock, grapefruit, tangelo, and mandarin orange seedlings tend to form low and bushy heads and usually require considerable pruning.

## BUDWOOD FROM SELECTED MOTHER TREES

Buds for propagation should always be taken from carefully selected trees of the variety desired: it is not sufficient to know merely that the buds are being cut from trees in a good grove of the variety. This necessity for exercising careful selection in the choice of mother trees rests primarily on two considerations: first, the variation in varieties and the consequent importance of taking buds from trees of the best strain of the variety; and second, the transmission of virus diseases and the desirability of being certain that the scions are from healthy trees.

As for the first of these considerations, it may be pointed out that bud sports frequently occur in all citrus varieties, and that these off-type sports are transmitted by bud propagation. This has been demonstrated beyond question. If, therefore, no tree and bud selection is exercised, poor and worthless types are certain to be propagated frequently.

All trees from which buds are to be cut should be very carefully examined while they are carrying a full crop of mature fruit, and buds should be taken only from those trees that are found to be vigorous and productive and to bear only good fruits typical of the variety. If the tree is found to bear abnormal fruits, it should be discarded as a source of budwood.

Much has been written on the desirability of taking budwood from performance-record trees (see Vol. I, chap. x; also Shamel, 1920). The policy cannot be too highly commended, as it is only by following the production and character of the fruit through several years that a complete understanding of the heritage and capacity of a tree can be obtained. That it is necessary to take buds from high-yielding trees has frequently been questioned, on the grounds that yield is in large measure determined by environmental factors. This may be granted, but the fact remains that some strains or varieties naturally produce higher yields than others. A tree may be of low or moderate yield by reason of poor rootstock or poor soil; yet the character may possibly be inher-

ent in the strain, and if so, it would be transmitted by budding. Thus, the policy of taking buds only from high-yielding trees is a safe one, and the only one that can be advocated as reliable.

As for the second consideration, the importance of choosing mother trees which show no indication of disease, little has been known until recently. It has now been demonstrated by Fawcett (1938, 1939, 1943) that citrus trees may be affected by a number of virus diseases which are transmitted by tissue transplantations, as by budding and grafting. Among these are such serious maladies as scaly bark (psorosis), concave gum disease, and others. Some trees that are still vigorous and productive may have contracted such diseases and, if used as a source of budwood, would spread the disease to many or all of the bud progeny produced. In a circular letter of December, 1941,[1] Fawcett stated:

"Prevention of psorosis A, psorosis B, concave gum, blind pocket, infectious variegation, and crinkly leaf consists in *planting trees propagated from buds taken from virus-free bud parents.* As far as known, none of the diseases spread from diseased to healthy trees under orchard conditions except by possible root grafts with an adjacent tree. To insure freedom from potential psorosis and other related diseases, buds for nursery trees should come from trees registered by the Bureau of Nursery Service of the State Department of Agriculture. More than 700 such trees have been registered and others are in process of inspection and registration. Growers are advised to ask the nurserymen for a written statement that trees purchased come from registered trees and to obtain the registration number and location of the parent tree. The rootstocks should also come from seeds from virus-free trees, although seeds rarely transmit the virus." (See also Fawcett, 1939.)

It is evident that the widespread occurrence of scaly bark in almost all citrus-growing regions of the world has resulted from its spread through variety propagation. The taking of budwood and scions from known healthy trees, carefully chosen, is therefore highly important (see chap. iii, below).

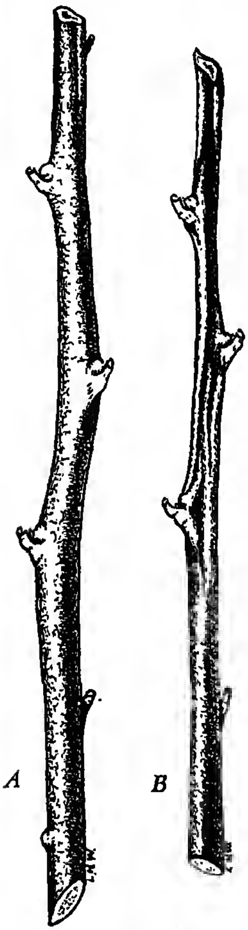
In general, it is best to produce nursery trees in the localities where they are to be planted. Trees produced locally can be planted more promptly than those brought from a distance, and the danger of injury during shipment is avoided. Furthermore, local trees are likely to carry only the pests and diseases that are already in the locality, and thus do not ordinarily require disinfection.

### TYPE OF BUDWOOD TO BE CHOSEN

Budwood should always be chosen from fairly well-matured wood of the current year's growth. Citrus trees usually have from two to three distinct periods of growth each year, and budwood from the last or next to the last growth is preferable. Round twigs, or those as nearly round as possible, should be selected. The young growth of citrus wood is at first angular but becomes more nearly round as the twig matures. The basal portions of young branches which are nearly or quite round (fig. 4, *A*) supply the best buds, with the

[1] Mimeographed circular letter by Dr. H. S. Fawcett, California Citrus Experiment Station, dated December, 1941. Consult also Fawcett, 1939, and Fawcett, 1943.

exception of the first one or two basal buds, which are usually somewhat imperfect and should be discarded. Where it is difficult to obtain well-rounded wood, angular wood may be used, but it is not so satisfactory since it is less easy to employ and is likely to be too immature (fig. 4, *B*).



*A* *B*

Fig. 4. Types of citrus budwood: *A*, round, mature twig of the preferred type; *B*, angular, less mature twig, which may be used.

Thorny budwood should never be used if other budwood can be obtained. Most of the standard citrus varieties are now nearly thornless, and it is commonly believed that this condition has resulted from the continuous selection of thornless budwood. Some varieties, such as the Lisbon lemon and the Parson Brown orange, still remain thorny, and newly introduced seedling varieties are usually thorny at first. Since thorny trees are undesirable, every effort should be made to choose budwood as nearly thornless as possible (see Vol. I, p. 825).

On the much-debated question whether to use only the so-called "fruit-wood" twigs in propagation, or whether "sucker" wood can also be used satisfactorily, the evidence is fragmentary, and at present definite conclusions cannot be stated. There can be no doubt that both types of wood carry the same heritage, and the writer knows of no convincing evidence to indicate that sucker wood is more likely to throw sports than any other type of wood. There is apparently no marked difference between the two types of wood, other than a physiological one related to rate of growth as determined by position.

Reference is frequently made to three types of wood: fruit wood, intermediate wood, and sucker wood; the names indicate clearly the relationship. Sucker wood is merely the rapid-growing wood of the suckers that spring out from the main trunk or main branches of the tree and grow very rapidly up through the top. Such suckers are large and coarse, with very large leaves, and are of continuous rather than of periodic growth. The small, rounded twigs of the typical so-called "fruit-wood" growth, with short internodes, small leaves, and very compact tissue, are quite different from the typical sucker wood; but there are all degrees of intermediate types of twigs or wood on the same tree. The sucker branches, probably because of their location, spend all their sustenance in vegetative growth to fulfill their function in rejuvenating the top. The fruit-wood branches, on the other hand, grow slowly in marked cycles or periods, store their nutrition, and are thus prepared when the proper season comes to develop flowers and fruits.

Halma's (1934) experiments with respect to size and age of budwood seem to indicate that these factors have little or no influence on the size of trees produced. He tested seven different sizes of budwood, ranging from 3 to 11 millimeters in diameter, in relation to the size of yearling Valencia budlings produced. The diameter of the sticks of budwood was found to have no influence on the size of the budlings.

Halma (1934) also made comparative tests of buds from apical and basal halves of the same budsticks, and of budwood from two distinct growth cycles developed during the same year. No significant difference was shown in the size of the one-year-old Valencia budlings produced.

Some have advised that budwood should be cut only from twigs bearing typical fruits, on the grounds that such bearing is reliable evidence of their type and fruiting capacity. The writer thinks this view an extreme one. Evidence from long years of experience throughout the industry shows that budwood taken from well-rounded twigs of the current year's growth of what may be termed the "intermediate" type of wood—which, nevertheless, approaches possibly more nearly the fruiting type of growth—is perfectly safe to employ for propagation, if from a properly selected nonsporting tree. Apparently the very large, succulent sucker-wood type of growth should not be chosen for budwood; but, on the other hand, there seems to be no valid reason why propagating wood should be taken solely from the small fruit-bearing twigs, which are so small as to be difficult to handle.[1]

## CUTTING AND STORING THE BUDWOOD

Budwood should be cut while the wood is dormant, before the buds show any signs of pushing. That which is desired for spring budding should be cut in the late winter, before the buds begin to grow, or, if in a locality where there is danger of frost injury, in the late fall or early winter. At all other seasons, as for the main budding period in the fall, the buds can usually be cut without difficulty just before they are to be used; but care must be exercised to select a time when a large proportion of the buds are dormant. As the twigs are cut, the foliage and thorns (if present) are carefully pruned off and the twigs are cut to the desired length for storage. The budwood should then be tied in small bundles and carefully labeled with the variety name, tree number, and like data. A mixture of varieties can easily occur, and damage may result from an error in name; hence, the utmost care must be taken to keep the records correct.

Budwood that is to be kept until needed may be carefully packed in boxes with moist sawdust or shingle tow, preferably from redwood or cypress, or, if these materials are not available, with moist sphagnum or peat moss. Whatever material is used, it should be merely moist and not wet and should be closely packed around the budwood. The boxes should then be closed and kept in a shaded, cool place. If budwood is to be held for several weeks or longer, it is well to bury the boxes 8 or 10 inches under the ground in a shaded, cool spot. Some simply bury the budwood in the soil under shelter, digging down

[1] Opinion differs on this matter. The reader is requested to consult statements made in Vol. I, chap x.

until the moist earth is reached. The objection to this method is that the soil particles adhere to the wood and dull the knife in budding.

If budwood is cut in the late fall to be preserved for spring budding, it is better not to tie it in bundles, but to spread it out loose in the boxes, in layers alternating with layers of the packing material, so that each stick will come in close contact with the packing. The boxes are then closed and buried as described above.

### MATERIALS AND TOOLS USED IN BUDDING

In citrus budding, almost any method employed with other plants can be used, but experience has shown that certain methods are especially applicable. To prevent buds from drying out after they are inserted, and to protect them from being injured by rains, it has been found best to wrap and cover them completely with strips of waxed cloth. The cloth must be ready in sufficient quantity before the budding begins. A good, strong grade of muslin which has been saturated with budding-cloth wax is used. In California, budding cloth can be purchased from almost any horticultural supply company. The budding cloth is torn into strips of the desired width and length as it is being used in the field.

The only tools needed in budding are a good budding knife, of which several types are available (see, for example, the knife blades in figs. 5 and 7), and a good whetstone and a hone for keeping the knife sharp. The use of a sharp knife in budding is the secret of success. It is usually desirable for the budder also to carry with him in his budding kit a pruning knife, or small pruning shears, with which to remove limbs or thorns that may have been left on the stocks when they were pruned in preparation for budding. Some sort of handy box or kit for carrying the supply of budwood in the field should also be provided, in which it may be kept moist under damp moss.

### HEIGHT OF BUDDING

The buds are inserted in the trunks of the small stock seedlings near the ground. In Florida, before the severe freezes of the winter of 1894–95, the general practice was to insert the buds at a height of 10 to 12 inches above the ground. Since then, the tendency has been to bud at a height of 4 to 6 inches above the ground, so that the trees may easily be banked with earth above the bud as a protection against injury and loss of buds from freezing. In California, the practice of budding low (4 to 6 inches above the soil) has also been that most generally used, though not apparently for the same reason. The bud union on trees in California is usually no more subject to frost injury than the rest of the top, and trees are seldom if ever banked at any stage in their growth.

The bud union is apparently a weakened area, commonly more susceptible to disease infection and injury than other parts of the trunk; and therefore it seems best to keep the union well above the ground. Nevertheless, certainly more than half the orchard trees in California are set so low that the bud unions are below the soil, owing both to overdeep planting and to low budding. Nurs-

erymen generally prefer to insert the buds low since this permits the budding of younger and smaller seedlings.

If trees are propagated on resistant stocks, such as the sour orange or the Sampson tangelo, in order to forestall injury from such gummosis diseases as foot rot or mal di gomma, much of the advantage is lost if they are budded so low that the susceptible tissue of the scion is brought close to the surface of the soil, where infection most commonly occurs. Gummosis diseases cause great injury in many parts of the world, and where there is little danger from frost it is clearly an error to bud too low. In general, the tendency has been to bud too low, and it would seem best to advise higher budding, at from 6 to 10 inches, or even more, above the soil.

## INSERTING AND WRAPPING THE BUDS

Budding is a wonderful but simple process, consisting merely in the insertion of the bud of a desired variety under the bark of the stock seedling in such a way that the freshly cut inner bark of the bud comes in close contact with the layer of growing wood cambium of the stock. As the bud is inserted, the bark closes partly over it, and the stock is wrapped with waxed cloth so that the bud is firmly pressed against the growing cambium of the wood. If the operation is properly performed, the tissue of the bud and stock soon fuse or grow together (see pp. 24–28), and the bud can then be forced to grow.

For all varieties and stocks of citrus the process of budding is practically the same, the method commonly employed being that known as shield or eye budding. The buds are inserted in the stocks 6 to 10 inches above the ground. All leaves and limbs which would hinder the proper wrapping of the buds should be cut away with a sharp pruning knife.

Two methods of inserting the buds are in common use: either the incision on the stock is made in the shape of the letter T and the bud is pushed downward into the cut, or the incision is made in the shape of an inverted T (⊥) and the bud is pushed upward into the cut. Professional nurserymen usually employ the vertical-T cut, and almost all amateurs and horticulturists the inverted-T (⊥). Claims of superiority for one or the other method have frequently been made, but extensive observations over many years have convinced the writer that, so far as the resulting trees are concerned, either method is just as good as the other. Thus the operator may use whichever method seems quicker and easier to him.

In applying the inverted-T method, a vertical cut about 1½ inches long is made at the point where the bud is to be inserted, and at the base of this cut a horizontal or slightly curved cut is made crosswise, so that the two cuts present the appearance of an inverted T (⊥), as shown in figure 6, *A*. The cuts should not be deep. The aim should be merely to cut through the bark—although little injury will result if the cuts are slightly deeper. To facilitate the insertion of the bud, the bark at the base of the cut is slightly raised with the point of the knife blade. This may also be accomplished by giving the blade an upward turn after the horizontal cut is made. Next, a stick of budwood is taken in the hand and held with its base toward the operator. The bud is cut

out by a long, sloping cut (fig. 5). One skilled in making this cut will retain the bud in position between his thumb and the knife blade so that he can insert the upper end of the bud and push it under the slightly raised ends of the T-cut on the stock without changing the position of the bud in his hand after cutting (fig. 6, *B*). The bud is then gently pushed upward by placing the back of the budding knife below the leaf petiole and exerting a slight pressure until all parts of the cut face of the bud come in contact with the wood of the stock (fig. 6, *C*). The bud is then ready to wrap. If the stock seedling is in proper condition for budding, the bark readily separates and allows the bud to be pushed upward into position. If the bark fails to slip readily on even a small proportion of the trees, all budding should be discontinued until the stocks are in proper condition.

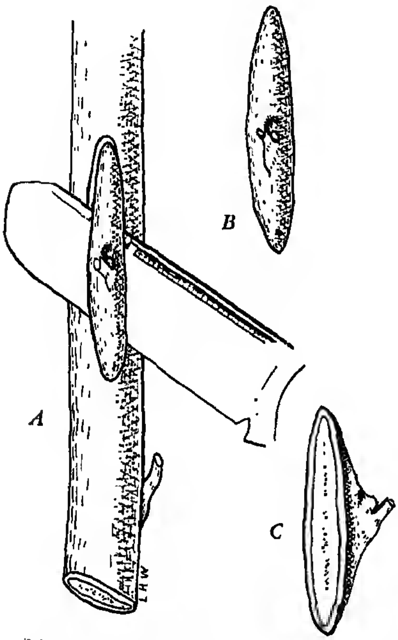



Fig. 5. Budding by the inverted-T (⊥) method: *A*, cutting the bud (base of budstick held toward the operator); *B*, the bud, ready for insertion in the stock; *C*, cut surface of bud, showing layers of bark and wood.

For wrapping the bud, the operator uses a strip of the waxed cloth ¼ inch to ⅜ inch wide, prepared as previously described (p. 18) and torn to the right length for the size of the stock. From just below the horizontal cut the cloth is wrapped tightly around the stock over the bud, and upward spirally so that each turn slightly overlaps the previous one. The wrapping must be drawn tight to hold the bud firmly against the stock, the wax holding the cloth in place. When the vertical incision has been entirely covered the end of the strip should be turned slightly downward over the wrapped part, to which it will adhere more firmly than it would to the bark. In many regions, as in Florida, tying is unnecessary. In California, however, where the humidity is low and a different kind of budding-cloth wax is used, the general practice is to wrap the buds in such a way that the two ends of the cloth may be brought together at the finish and twisted to hold the wrapping securely in place. When this method is employed, the first turn is made below the lower end of the wrap, and the second turn over the first one so as to leave about one inch of the end exposed; and then, after the bud and the vertical cut are entirely covered by an upward spiral, the wrapping is spiraled downward until the two ends can be brought in contact and twisted together (fig. 6, *D*).

When the vertical-T method of budding is used, the operations are in general the same as for the inverted-T method, but reversed. The horizontal cut

is made at the top of the vertical cut instead of at the bottom. In cutting the bud (fig. 7, *A*) the apex of the budstick is held toward the operator and the bud is cut by a draw of the knife from the base of the bud toward the apex, so that, when the bud is cut and held in the hand between thumb and knife blade, its base is exposed and ready to be inserted in the stock incision and pushed downward into place (fig. 7, *B*). Another difference is that in wrapping the bud the operator begins above and wraps downward to push the bud

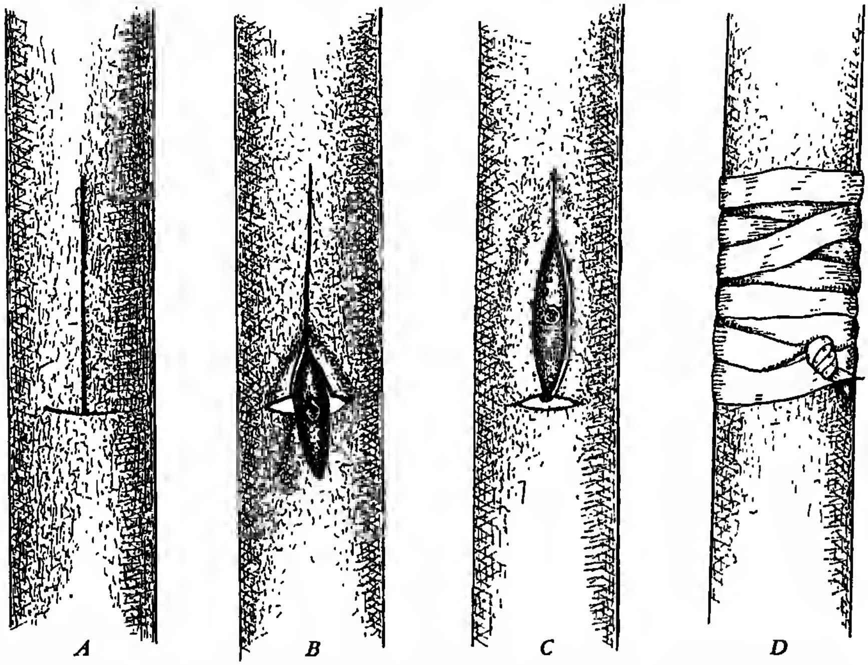


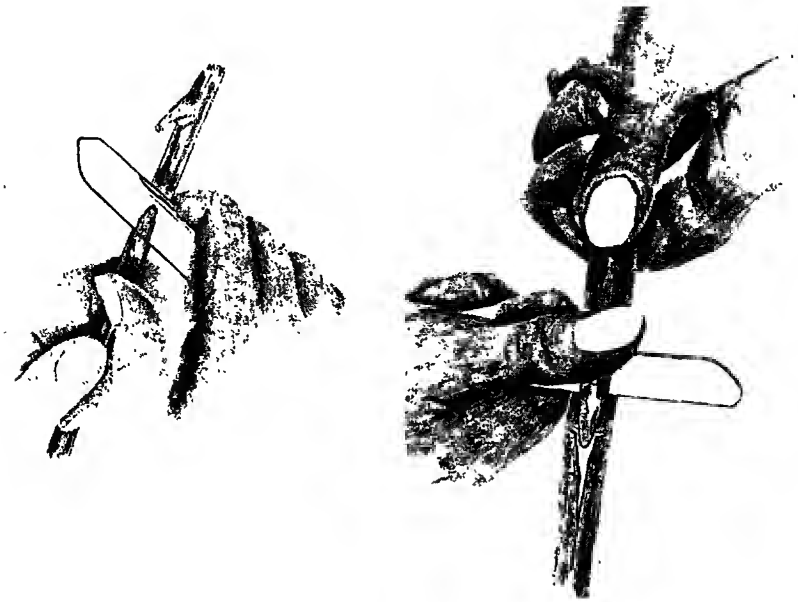

Fig. 6. Budding by the inverted-T (⊥) method: *A*, vertical and horizontal cuts in the bark; *B*, bud partly inserted; *C*, bud fully inserted and ready to be wrapped; *D*, bud wrapped with waxed cloth the ends of which are twisted together to hold wrapping securely in place.

into the cut in the stock (fig. 8); if he began below and wrapped upward, as in the vertical-T method, he would push the bud out. Here, also, after the bud and vertical cut are entirely covered, the wrapping is spiraled around the stem until the two ends of the wrap can be brought in contact and twisted together.

In cutting the buds as described above, a bit of wood is cut out with the bud. In early days of budding, this was removed before the bud was inserted; but experience has shown that the removal is unnecessary; indeed, the presence of the wood makes it easier to insert the bud, and better results are obtained by leaving it.

Where budwood of certain varieties is difficult to obtain, it may be desirable

to use buds from the young angular wood usually present on the tree in considerable quantity (fig. 4, *B*). Even rather immature angular wood may be used with good results if the stock to be budded is growing rapidly and is in a succulent condition. The method of cutting and inserting the bud is now slightly different from the methods already described. In cutting the bud, the stick is turned slightly to one side so that, as the bud is cut off, the eye lies to



*A* *B*

Fig. 7. Budding by the vertical-T (T) method; *A*, cutting the bud (apex of budstick held toward the operator); *B*, inserting the bud by pushing it downward into the cut, the operator standing over the tree.

one side instead of in the center (fig. 9, *A*). It is only by cutting the bud in this way that the cut surface is made wide enough to allow the bud to be held firmly in position. The incision made in the bark of the stock is the same as that made by either method previously described, but the bud is inserted under one flap of the bark only. The bark is raised on the left side with the point of the knife, and the bud is slipped under in a slightly lateral direction, the eye remaining in the vertical slit (fig. 9, *D*). The wrapping must then be put on in such a way as to tend to crowd the bud under the bark rather than out of it; this means that it should be passed around the tree trunk in the direction in which the bud is shoved into the incision.

Success in budding depends upon the use of a sharp knife and upon the performing of all operations quickly but not hurriedly. The cut surface of the bud is easily injured if left exposed to the air. One can soon develop the

necessary skill to insure good results. Good budders can expect at least 95 per cent of the buds to take (heal on) and can insert 1,000 or more buds per day. Ordinarily, it is not good policy for the budder both to insert and to wrap the buds: he should be followed by a wrapper (fig. 8), and the two operations should be timed so that each bud is wrapped promptly before it has time to dry out.

Fig. 8. Budding and wrapping by the vertical-T (T) method: the budder (*right*) is in position to insert the bud and is followed by the wrapper (*left*).

UNWRAPPING THE BUDS

From 10 to 14 days after the buds are inserted, they should be unwrapped and examined to determine their condition. The stocks are usually growing rapidly, and if the tightly drawn wrappings are allowed to remain too long the new wood may grow over the buds and greatly hinder their development. If, when unwrapped, a bud is found to be still green, and if a grayish line of new tissue can be seen forming around the edge of the incision, it may be concluded that the bud is living; the wraps should then be replaced less tightly. If on some stocks the buds are found to be discolored and dead, the wraps should be removed; the stocks may then be rebudded. When the buds are thoroughly healed on, the wrappings are taken off entirely. A little experience will enable one to tell at what stage it is safe to remove them: with spring and summer budding, 20 days is usually long enough; in the fall a slightly longer period is usually required, probably from 25 to 30 days.

PROTECTION OF BUDS FROM FROST INJURY

Where dormant budding is practiced in localities subject to frost injury, the buds are often protected by throwing a bank of earth up around the bases

of the stock seedlings in the late fall, high enough to cover the buds. This may be done with a plow. The earth is pulled down again in late winter, as soon as the danger from freezing is past. This practice is common in Florida but is not used in California.

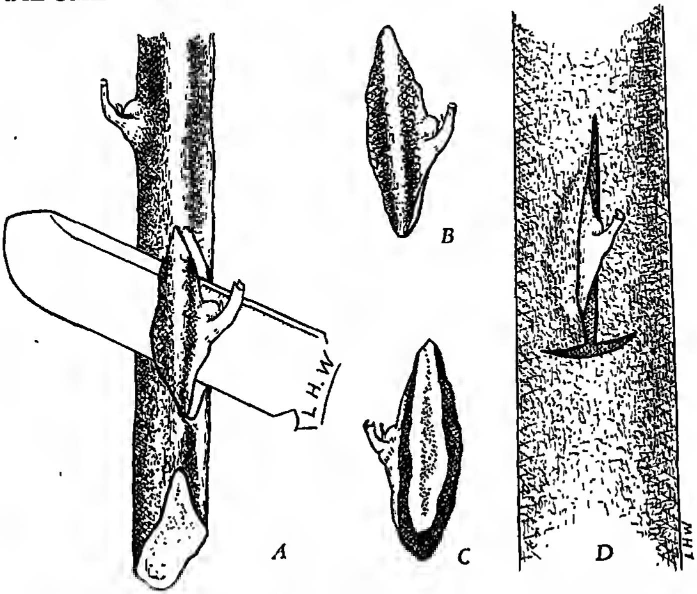



Fig. 9. Side-slipping angular-wood buds: *A*, cutting the bud; *B*, bud cut, showing position of bud and leaf stem; *C*, cut face of bud; *D*, bud inserted in stock.

## THE HEALING-ON PROCESS IN CITRUS BUDDING

Although the technique of citrus budding has been highly developed, little has been known about the healing-on processes. Recently, the tissue developments have been carefully investigated by Kurt Mendel (1936, 1937), in Palestine. For this study he used buds of Shamouti orange on rootstocks of Palestine sweet lime and sour orange. The following is a summary of Mendel's findings.[1]

### THE WOUND SCAB

The formation of a wound scab, or insulating layer, in plants has commonly been described as the first reaction following budding or grafting. This layer, formed by the walls and contents of the injured cells, which break down and turn brown in color, has been supposed to act as a temporary closing of the wound, protecting the inner tissues from drying out. Tests showed that in citrus these layers always consist of gum. Mendel (1936, p. 28) described the formation of gum as follows.

[1] This discussion on the process of bud healing is taken almost verbatim from Mendel's (1936) report, but frequently is not indicated as quoted because it is slightly changed and shortened.

"The transformation of dead cells to wound gum is only slight if the wound is well closed by the wrapping. The outer cells of the callus tissue, as well as the cells of tissues adjacent to the wound forming no callus, . . . are crushed and transformed into gum due to steadily growing pressure of the joining callus masses. Tissues which are apparently particularly active, such as the medullary rays, prevent a formation of continuous gum layers. . . .

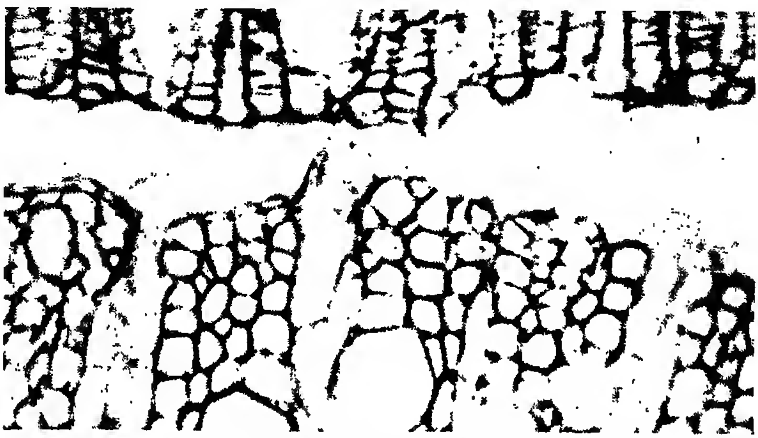


Fig. 10. Cross section through a bud union of Shamouti orange (*above*) on sour orange stock (*below*), 24 hours after budding. Note the newly formed cells at the ends of the medullary rays. These cells are pushing out into the space between the bud and the stock, and are most clearly visible on the stock. × about 330. (After Mendel.)

"The formation of the insulating layer in citrus buddings is, therefore, not a primary wound reaction, but a secondary phenomenon which appears under the pressure of the uniting callus tissues."

## FORMATION OF CALLUS

The first stage in the healing after the operation of budding is, according to Mendel (1936, p. 21), the closing of the wound by the formation of callus tissue. The first cell divisions marking the beginning of callus formation occur very soon after the operation, the time being dependent upon external factors, especially temperature. In the 1930 tests new cells were found after 24 hours; but in the 1932 tests there were no new cells at 36 hours, and none were observed until 42 hours after budding. Cell divisions begin almost simultaneously in all tissues adjacent to the wound, on stock and scion alike.

The first new divisions start almost regularly at the injured ends of the medullary rays on the surface of the wood, as well as on that of the bark. Not until later do the cells of the wood parenchyma and those of the secondary bark take part in callus formation.

The new cells may be clearly seen bulging out at the ends of the medullary rays of both rootstock and scion bud (fig. 10). The growth of callus takes place

through the stretching of the newly formed cells at the periphery, which become club-shaped and form new cross walls. Longitudinal divisions may also occur, particularly in cells that are free to extend in any direction, that is, with the first callus cells of the medullary rays, which grow into the gap between the tissues. Thus, the wedge-shaped broadening of the medullary rays at the wound surface is effected (fig. 11).

In budding (without wood), three cavities are created in the wound area and are gradually filled by the growth of callus. Two lateral cavities are formed by the raised bark flaps, and a central cavity is formed beneath the

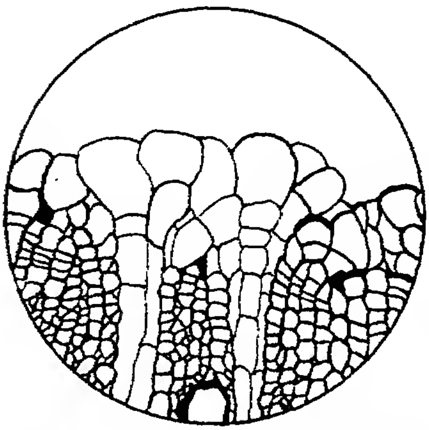


Fig. 11. Cross section through the callus on a sweet lime stock 3 days after budding. Note the wedge-shaped broadening of the medullary rays, much extended over the development shown in figure 10. (After Mendel.)

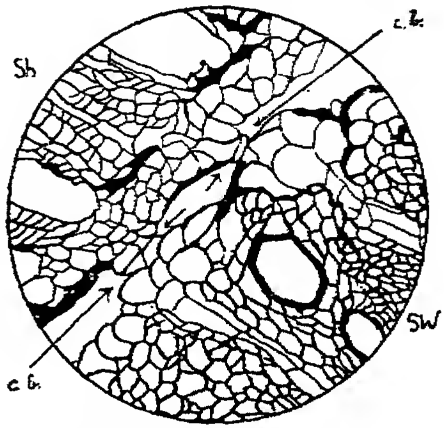



Fig. 12. Cross section of bud union of Shamouti on sweet lime 5 days after budding, showing the formation of callus bridges leading from the wood to the raised flaps. *Sh*, Shamouti; *SW*, sweet lime; *c.b.*, callus bridges. (After Mendel.)

shield at the place of the former vascular connection of the bud, the so-called "bud cone." As these cavities become nearly filled by the expanding callus tissue, bridges of connecting cells are formed from the stock side to the bud side (fig. 12). The cavities under the flaps at the side of the bud shield are filled after about 20 days; the cavity beneath the shield is filled after some 25 days or more.

The actual process of the union of tissues in which interest centers, Mendel (1936, p. 25) described as follows: "The meeting callus masses grow together by the union of the cell walls of the meeting cells thus producing one gapless tissue. The border between the united callus masses can be recognized only in cases where a brown layer forms in the border zone [the compressed remnants of wound scab]. Cell fusion was not observed." The walls of the growing callus-tissue cells as they come together from the opposite sides, that is, from stock and bud, become closely appressed under pressure, so that they adhere and become as intimately attached and connected as are cells in any normally growing tissue.

### DIFFERENTIATION OF TISSUES IN THE CALLUS

The callus tissue is at first completely uniform, consisting entirely of isodiametric cells. Within about 10 days cellular differentiation begins to appear, the walls of some of the cells becoming thickened and beginning to show pits. Callus cells that have been transformed into tracheids may be observed in the callus of the flaps after about 15 days. Differentiation under the shield is slower, the first tracheids being observed only after 20 days.

### REGENERATION OF THE CAMBIUM

The establishment of a common cambium ring for rootstock and bud is either a process of regeneration underneath the flaps and the shield where the cambium has been either injured or torn away, or one of differentiation where the cambium layers are connecting in the callus. The cambium is always regenerated in the outer region of the callus; that is, it is always close underneath the secondary bark of the shield or of the rootstock, respectively. Old cambium cells which remain on the wood of the rootstock lose their meristematic properties and differentiate like callus cells, even if no cambium is present on the shield. According to Mendel (1936, p. 31), it could not be seen, in the sections, whether the cambium regenerates from the outer cells of the callus or from the innermost uninjured cells of the secondary phloem.

Formation of the connecting cambium is completed after about 25 days. At this time the process of the union of the citrus bud may be considered complete.

### CONNECTION OF VESSELS

The primary need of the scion, after budding, is water supply, and in a very primitive way this is accomplished by the first callus bridges. Afterward, the differentiation of the tracheid strands in the callus assures the water supply to the shield. The first system of water supply is, therefore, based not on a longitudinal but on a lateral connection.

But this type of water supply to the shield cannot suffice for the sprouting of the bud. The connection of the bud with the wood of the rootstock has to be established through vessels before sprouting. This connection is originated in the cambium which is formed in the callus below the shield.

Mendel stated that no fundamental anatomical differences were observed between the union of Shamouti with sweet lime and sour orange, respectively.

### DISCUSSION OF MENDEL'S FINDINGS

Budding as practiced in Palestine in the propagation of the Shamouti orange is mainly by means of bark bud-shields from the scion, without wood. This, Mendel terms "true shield budding," and his anatomical studies were conducted almost wholly with such propagations. From his studies he concludes that budding of citrus should be done "without wood" and with the shield as large as possible, and that, where budding "with wood" has to be resorted to, the shield has to be cut rather thin.

This statement might be disconcerting to growers in California, Florida,

and Texas, where the largest citrus acreage in the world has been successfully developed and where the many millions of trees of all varieties of oranges, lemons, grapefruit, and other citrus species have been almost wholly produced by using buds with a wood core. Expert budders pay little or no attention to the thickness of the layer of wood cut with the bud, other than to keep the bud piece thin enough to lie fairly flat and not protrude too far above the surface when inserted under the stock bark. The success of such budding is beyond question, for the citrus orchards of the United States are recognized as among the best, and are perhaps the longest in productive life of any in the world.

Mendel's studies do give us a valuable and interesting understanding of the healing-on process. It is unfortunate that his investigation was not extended to the healing of buds with wood cores. Mendel observed that the first and most active development of callus, as well as the first regeneration of the cambium, is at the edge of the bud, under the bark flaps of the stock. It seems probable, thus, that in buds with wood cores the cambium remains uninjured except at the edges, and that it probably unites at the sides or edges with the new cambium developing in the callus under the bark flaps. It would then continue active in the further bud development. The small slice of wood of the original bud then probably breaks down into wood gum and, forming only a very thin layer running longitudinally to the stock stem, probably causes no interruption in the growth. Indeed, it seems probable that the use of buds with wood cores may even accelerate the completion of the union, as they would require merely the fusion of the cambium connections at the edges of the bud, and not all over the cut face of the bud; furthermore, the normal connection of the original cambium of the bud with the bud structure has not been interrupted.

No detailed studies have been made of the fusion processes in the various types of citrus grafts to be described later, but in general the fusion processes doubtless correspond closely with the phenomena exhibited in budding. In the scions of grafts, it is certain that the old cambium is not regenerated, but that it must fuse directly at the contact edges with the cambium of the stock.

A knowledge of the tissue developments in the fusion of scion and stock may be important in understanding the transmission of those virus diseases which infest only certain tissues. A virus that develops only in the xylem (wood) might be expected to be transmitted by the scion in grafting, because the new scion wood unites with the wood of the stock. However, a virus limited to the xylem probably would not be transmitted by budding, as the wood core of the bud at no time forms any connection with the wood of the stock, but remains surrounded by callus tissue until it is broken down and transformed into gums.

## GROWING THE BUDDED TREES OR BUDLINGS

### FORCING THE BUDS

In order to force the buds to push uniformly after they have healed on, it is necessary to check the growth of the stocks. In citrus nurseries this is

usually done in one of two ways: either by topping, that is, by cutting off the tops a few inches above the buds, or by "lopping" the tops, as it is called. The former method is that most commonly used by nurserymen; the latter has been used in some degree both in Florida and in California and is to be recommended in special cases.

When the topping method is used, the entire top of the stock is cut off, with pruning shears or saw, from 3 to 5 inches above the bud. In fall-budded trees, in which the buds are expected to remain dormant through the winter, the topping should be done in the early spring after the danger from freezing is past and just before growth starts. In spring- or summer-budded trees, topping is usually done from 3 to 5 days after the wraps are removed from the buds. No further attention is then necessary until the buds begin to grow.

Fig. 13. A nursery tree lopped to force the bud.

Buds will push out all around the top of the stock stump, and pains must be taken to keep these rubbed off and to permit only the sprout from the inserted bud to grow; otherwise, a sprout from the stock may be mistaken for the bud and allowed to grow.

The lopping method differs from the preceding in that the top of the stock, instead of being entirely cut off, is left partly attached for a considerable period (fig. 13). Lopping is performed at the same time as topping, and is done mainly with pruning shears, the knife edge being placed 3 to 4 inches above the bud and the stock cut about two-thirds through. The cut is made on the bud side, in order to check the transfer of materials in the stem on that side. The top is then bent over and allowed to rest on the ground. In bending or breaking the top over, one must make sure that, if the stem splits, the splitting is upward rather than downward toward the bud.

To provide for subsequent cultivation and care of the trees in the nursery it is necessary to follow some definite plan of budding and lopping. Two methods are commonly used. In the one, the tops of two adjacent rows of trees are lopped into the same middle (space between rows) (fig. 14, *A*), and alternate middles are kept free for cultivation and tree care. The buds of each two adjacent rows must, therefore, be placed on opposite sides of the stocks (see fig. 14, *A*), facing the middles retained open for care and tillage.

In the other method, the buds are all placed on the same sides of the stocks; but, in lopping, the tops of alternate rows are bent in opposite directions, those of one row, only, occupying a middle (see fig. 14, *B*). The lopped tops must be bent inward close to the tree row in order to leave space for cultivation. A

cultivator may then be run up one row and down the next, always going in the direction in which the tops are inclined, as thus the branches will not interfere.

The tops are allowed to remain attached until the shoots from the buds have attained a height of 12 to 18 inches, after which they may be cut off. Some nurserymen have found that the budlings make a larger growth if the old tops are allowed to remain attached through the summer and are cut off in the fall. The principle involved in "lopping" is to retain for a while a con-

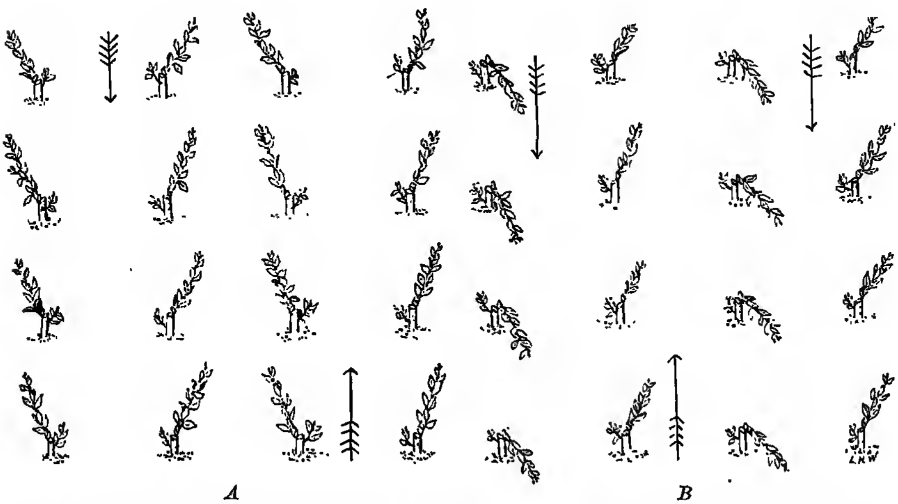


Fig. 14. Two methods of lopping nursery trees to facilitate cultivation: *A*, heads of two rows of trees lopped into same middle with alternate middles free for cultivation; *B*, heads of alternate rows lopped in different directions so that each middle may be cultivated. The arrows indicate the direction of cultivation.

nection between the old top and the roots, to supply some nourishment to the roots while the bud is developing.

Cutting off the entire top is a severe shock to the young tree, and several months must elapse before the bud can produce foliage enough to equal, even partially, that of the original top; meanwhile, the large root system of the stock must suffer nutrition deficiency. During the year of bud growth the stock trunk increases but little in size.

Topping is less bothersome and expensive than lopping, however, and is the method that should be followed unless something is to be gained by the use of the latter method. It is certain that good nursery trees may be produced by either method, for both have been extensively practiced.

In California, in two comparative trials known to the writer the lopping method gave somewhat larger trees in a season's growth than the topping method. It is probable that rather larger nursery trees can be grown within the same time limits by the lopping method; but in arid regions where furrow

irrigation must be used this method greatly increases the difficulty and adds materially to the expense.

The writer is inclined to the opinion that, where fall budding is practiced, the topping method, all things considered, is the more satisfactory of the two. If, however, for some reason spring budding is used on comparatively small stocks and year-old budlings are to be planted, the lopping method may preferably be used to bring the buds up to a desirable size for transplanting the next spring.

### STAKING AND TRAINING THE BUDLINGS

As the buds are forced out, they grow rapidly and the attachment to the stock is weak and easily broken. To protect them from breaking and to insure a straight trunk they are trained to stakes (fig. 15). The stakes may be made of any good durable wood and should be about 3½ to 4 feet long. In California, standard building lath is commonly used for this purpose.

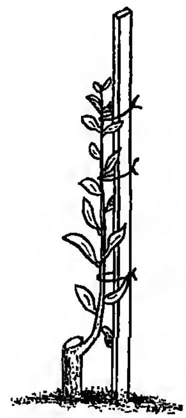


Fig. 15. Young nursery budling supported by stake driven into the ground beside it. (The flat side of the stake should be rather closer to the tree than is indicated.)

When the buds are well started and reach a height of about 6 inches, the stakes should be driven into the ground on the sides next to the growing buds and close to them. The stakes will usually be from 1 inch to 2 inches from the base of the stocks, depending on the uprightness of the shoots; the distance must not be so much as to encourage the growing shoots to make too great an angle with the stock trunk at its origin (fig. 15). The widest side of the stakes should be touching the shoots. When the stakes are set, the young shoots are tied to them with raffia, cotton twine, or narrow strips of cotton cloth. As the shoots grow, they are tied at distances of about every 4 to 6 inches, the ties being rather loose in order to avoid compression or scarring of the tender new shoot. To produce straight trunks, careful attention should be given to the tying, and all side sprouts on the main trunk of each bud shoot should be removed. It is also well, at each tying, to rub off the sprouts that form on the trunks of the stocks, in order to force all growth into the main trunks of the new trees. These sprouts form in great numbers and require removal about every three or four weeks during the summer.

When the bud shoots have reached a height of a foot or more, the stubs of the stocks remaining above the bud unions should be cut off smoothly just above and even with the buds. This may be done with pruning shears or saw, but the cuts must be made with care and should slope downward away from the buds (fig. 16). In any case, the surface should be smoothed with a sharp knife and should leave no projecting stubs above the buds. Immediately after the removal of the stub, the cut surface should be painted with shellac, or covered with a coating of preserving wax. The stubs of lopped trees are similarly cut back when the tops are removed.

### TOPPING AND HEADING THE BUDLINGS

As soon as the young budlings have reached the desired height, they should be topped, or cut off, to force the growing of side shoots and to start the development of the tree head or main branches.

In California the heads are formed mainly at 30 to 36 inches from the ground, while in Florida the general tendency is to form a somewhat lower head, about 24 to 30 inches. The main trunk of the nursery tree is usually permitted to grow several inches above the height of the head desired and is then cut back to the proper height. This method is preferable to that of pinching off the terminal bud when it reaches the required height. In some nurseries the trees are headed back to rather hard wood in the early fall, not later than the first of October, and again about February, to avoid having soft wood in the resulting heads.

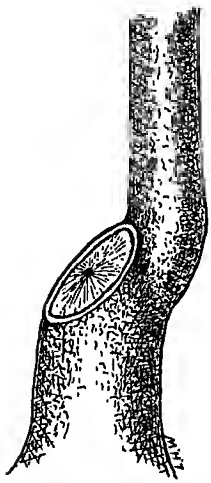


Fig. 16. Proper cut in removing stub of stock trunk above the bud union.

In general, the same methods of training and heading are practiced with all varieties and species of citrus fruits. With lemon varieties, because of their very vigorous growth in the nursery, the tendency is to head rather high, about 30 to 36 inches; Satsumas, on the other hand, because of their very slow growth, are usually headed low, at 18 to 24 inches.

After the budlings are first headed back, lateral shoots form freely along the upper part of the trunk, and three to five of these, properly spaced, will ultimately be retained to form the main branches of the new tree (see p. 34).

The general policy, after cutting back, is to let the branches develop freely without any special training or pruning other than the rubbing off of such buds as start on the lower part of the trunk and stock, until the time arrives to dig the budlings for transplanting.

## DIGGING AND PREPARING BUDLINGS FOR PLANTING

### SIZE AND AGE OF BUDLINGS

Budlings should remain in the nursery until one to two years after the time of budding, or until the trunks have reached a size, preferably, of from ⅝ inch to 1 inch in diameter (fig. 17). If the seedlings were from ⅜ to ½ inch in diameter when they were budded, and if they were fall-budded and forced early in the spring, the majority of the budlings should reach the required size in one year. If, however, smaller seedlings were budded, two years may be required to grow budlings of desirable size for transplanting.

Budlings that are of slow growth and do not reach the required size along with the majority of those in the same block are probably poor trees and should be discarded. If held longer in the nursery, such trees might ultimately

reach the required size, but frequently they are "runts" and are worthless. Size of budling is therefore no criterion of value, unless the exact age and the size in comparison with other budlings in the same block of stock are known.

METHODS OF DIGGING

Many different methods are used in digging and preparing nursery trees for planting, but all of them are variations of two general ones, the balling method and the bare-root method. Citrus roots are particularly sensitive to injury by drying out and must be kept continually moist; the method used must therefore be based upon this fact.

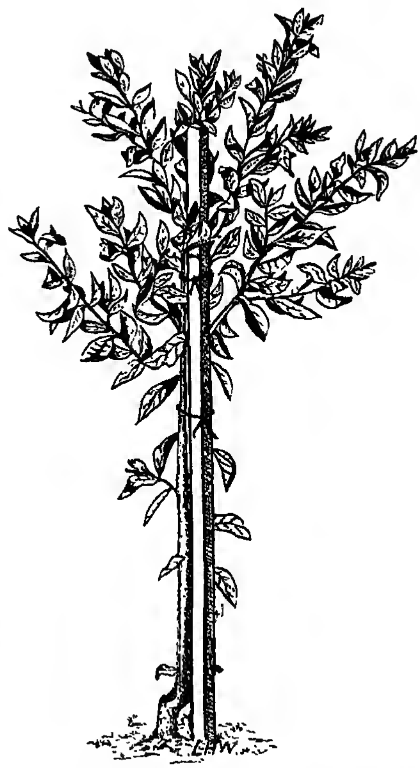


Fig. 17. A good year-old citrus budling ready to be cut back and transplanted.

Balled trees are those which are dug so that a clinging ball of earth surrounds the roots of the tree. In the ball a fairly large part of the root system is retained undisturbed in contact with the original soil, the lateral roots remain spread naturally in the soil, and many of the small roots continue to function. Balling is thus a method well adapted for use in arid or windy regions, where there is danger that the young trees may be injured by root exposure. If trees are to be shipped to a distance, the heavy ball of earth, which usually averages about 40 pounds in weight, adds greatly to the expense. It is, however, the method most generally used in California, where the trees are now commonly transported by motor truck. It is a thoroughly reliable and satisfactory method, though the root system transplanted is much smaller than that of trees dug and transplanted by the bare-root method. The balled budlings are much easier to handle in planting than bare-root trees, as there is not so much danger of their drying out and no care is required in spacing and spreading the roots in planting.

Trees transplanted by the bare-root method are, as the name of the method indicates, dug from the soil with a large part of the root system uninjured and with a minimum amount of soil attached. After some root pruning the trees are transplanted directly into the permanent grove. This method is used commonly in Florida and to some degree in California. It is the method always used if trees are to be shipped long distances. It is best adapted for use in humid countries and must be employed with great caution in arid countries.

### PRUNING AND PREPARATION OF BUDLINGS FOR DIGGING

The successful transplanting of any tree requires that it be severely pruned or headed back, and citrus budlings are no exception to this rule. Probably the best time to do the pruning and shaping of the head is in the nursery, just prior to the digging. At this time, carefully trained men should examine each tree and remove all branches but the three to five main ones that come from the central trunk and are to be left to form the head or main branches of the tree. These should be cut back to a length of 6 to 8 inches.

The question arises, from time to time, whether the heads of the budlings should be formed in the nursery, or whether it is better to prune them back to a single straight trunk of the desired height and form the heads in the orchard after the trees are transplanted. Cutting back to a single unbranched trunk permits each grower to head the trees according to his own ideas; and little if any time is lost by so doing, unless the branches of the head are fully mature twigs. On branches that are not mature the buds will not push in the orchard as soon as the buds on the main trunk do, and if too young they will not grow at all but will finally die and be supplanted by shoots arising from the main trunk.

The policy most generally pursued, however, is to form the heads of the budlings in the nursery. If the budlings are as old and as large as they should be before they are transplanted, they will have developed a number of branches on which the wood is well hardened and mature; obviously, it would be a loss to remove all this growth. It is thus generally thought best to prune back and shape the head in the nursery just before digging.

In order to get the greatest possible structural strength and prevent limb splitting when heavy crops must be carried, it is judged desirable that the main branches of the head should be separated at intervals of 3 to 4 inches apart along the upper 12 to 14 inches of the trunk, and so distributed around the trunk as to divide the periphery space about equally. It is seldom, however, that such an ideal distribution of the limbs can be realized. It would be entirely possible, if one could give the necessary attention to the removal of buds, to form a head of almost any type desired, but it is not feasible to do this with large numbers of trees. It is thus necessary when shaping the head to choose those branches for retention which present, in the grower's judgment, the best arrangement.

In practice, there is much variation also in the amount of foliage left on the budlings. Some growers remove all the foliage, a procedure which reduces the loss of water to a minimum; others allow some or all of the foliage on the short branches forming the head to remain (fig. 18). Those who follow the latter practice assert that it is important to leave some foliage in order to keep water moving up through the wood and to keep assimilation active; in their opinion, the tree is thus stimulated to quicker and more vigorous growth. This does not seem unreasonable, and is doubtless true if the root system is in proper condition and is large enough to supply the moisture necessary to prevent wilting. Leaving a limited amount of foliage (approximately as indicated

in fig. 18) is probably the most general practice followed in both California and Florida. In California, total defoliation is practiced only when the nursery trees are to be shipped into counties requiring vacuum fumigation before planting. Such defoliated trees, if not injured by the fumigation, are known to make satisfactory growth.

Removal of all foliage is advantageous in serving as a partial check on the spread of diseases and pests, since the leaves are most frequently the carriers. The defoliated trees should be dug immediately, or at any rate not long, after the pruning and before growth starts.

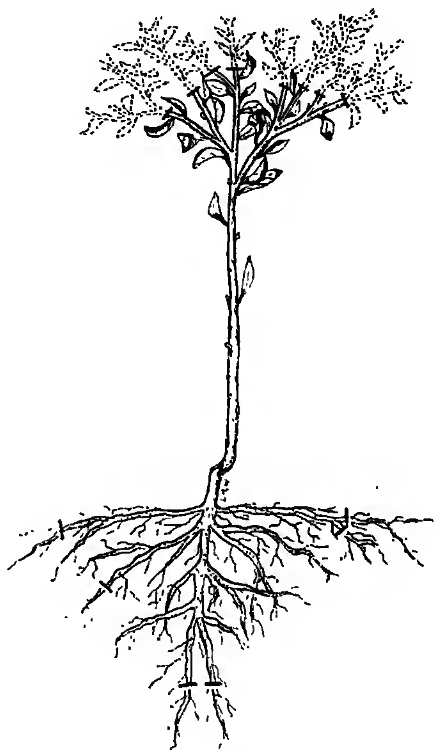


Fig. 18. Pruning of roots and top of budling for bare-root planting. The dotted outlines of branches and the bold straight lines on branches and roots indicate the parts to be cut off.

Some nurserymen prune back only in part the budlings in the nursery, leaving a rather large proportion of the twigs and foliage attached; they then ship the trees in this form, apparently on the assumption that the grower will desire to shape the tree head himself after planting. It is sometimes asserted that it is best to delay the final pruning until after the trees are planted; but this can hardly be good practice, for the extra twigs and foliage are an additional drain on the tree. It would seem that the water supply and the stored nutrition in the tree would best be conserved by the removal in the nursery, before digging, of all the foliage and branches that are to be removed. All the available energy would then be directed to the healing of the permanent cuts and the formation of new sprouts.

It should also be stated that it is not an uncommon practice in California to transplant budlings that are merely young, year-old whips cut back to a height of approximately 30 inches. On such budlings most of the leaves are retained, but all lateral branches are removed. Such trees require to be headed in the orchard after transplanting and this requires some extra work. The trees are also likely to remain for a while somewhat smaller than properly headed nursery trees. Some California growers express a preference for the use of such "whipstalk" budlings, but their use has not yet become the acknowledged best practice.

## DIGGING AND BALLING

When the budlings have been pruned back and are ready to be transplanted, a trench 14 to 18 inches deep is dug along one side of the nursery row at a distance of 6 to 8 inches from the trunks of the trees. As the trench is dug, the lateral roots are cut off with a sharp spade or, if they are especially large, with sharp pruning shears. At each tree the digging is sloped inward when the trench is deep enough to allow undercutting where the bottom of the ball is to be. The inward sloping exposes the taproot, which is cut off with pruning shears. The ball may be from 14 to 18 inches long in vertical dimension. There can be no doubt that the longer ball is the more desirable, but since the balls must be kept to moderate size, a 14-inch ball is that commonly used. After the taproot has been cut, a sharp spade is used to cut away the soil on all sides of the tree and shape a cylindrical ball of undisturbed earth around its base. This should be from 8 to 10 inches in diameter and from 14 to 18 inches in length. When the ball is shaped and the roots are cut off, the top soil is removed as far down as the depth at which the crown roots spring from the trunk. The budling is then lifted out and set in the center of a piece of burlap of such a size that when it is drawn up on all sides it will completely cover the ball. The edges of the burlap are gathered together around the base of the budling trunk and tied firmly with heavy binding twine; and ties are extended also around the ball vertically and horizontally to assist in holding it together unbroken (fig. 19). The size of ball used depends mainly on the distance to which the trees are to be shipped, the conditions of transportation, and the price at which trees are selling. The smaller the ball, the easier it is to handle and the less likely it is to crack and crumble down and disturb the roots. The larger the ball, the greater is the number of roots preserved; but the large-balled trees are more difficult to handle.

Nursery trees grown on heavy soil should not be balled if they are to be planted on a light soil. The irrigation water does not readily penetrate a ball of heavy soil surrounded by a light soil; and thus the growth is frequently interrupted and the tree injured. The soil close around the base of the tree is never disturbed in ordinary orchard practice, and the balls are thus not broken up. If the soil cracks on drying out, it usually cracks around the ball. The writer has seen trees twenty-five years old dug out of light soil with the balls of heavy soil surrounding the base still intact and about as plain in outline as when planted. Trees grown on heavy soils should be planted on similar heavy soils, or should be dug and planted with bare roots.

Balled trees, if not to be planted immediately, should be stood close together, under shade, and sprinkled frequently to keep the soil in the balls moist but not wet (fig. 20). In shipping, balled trees are stood upright on the floor of the car or truck and packed close together for support.

In handling balled trees great care is necessary to prevent the balls from crumbling and injuring the roots. It may take months of good growing conditions to overcome such injury. A balled tree should be lifted or moved either by taking hold of the ball itself or by grasping the burlap where it is tightly


*A* *B* *C*

Fig. 19. Digging and balling citrus budlings: *A*, the ball still in its original position, dug and shaped ready for wrapping; *B*, wrapping the ball; *C*, the budling fully balled and wrapped ready to plant or ship.

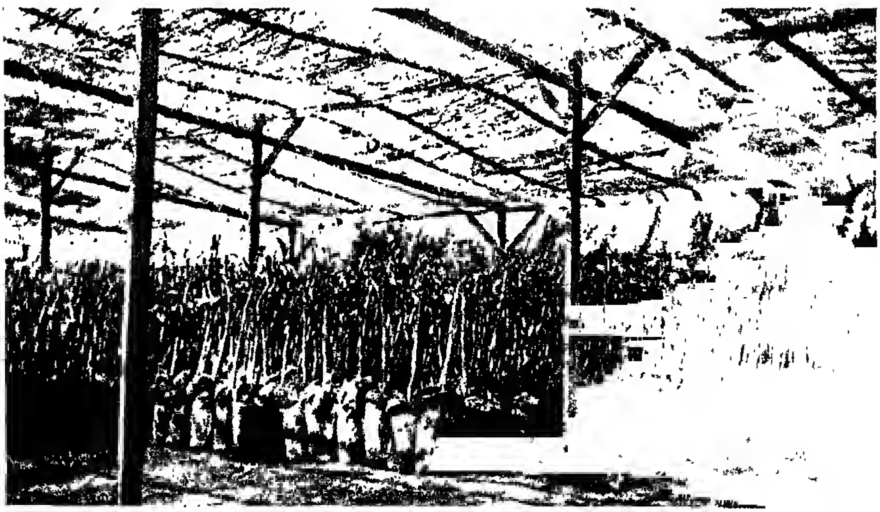


Fig. 20. Balled budlings stored in seedbed shed.

drawn together and tied around the base of the trunk at the top of the ball. Balls may also be broken down by overwatering. For successful moving of balled trees it is necessary that all workmen and truck drivers be carefully instructed and supervised.

### DIGGING BUDLINGS FOR BARE-ROOT PLANTING

Budlings for bare-root planting should be dug with care, pains being taken to preserve the roots with as little injury as possible. By the bare-root method a much larger root system can be used, only the ends of the main roots being cut off.

One careful nurseryman in California (Nusbickel, 1918), after much experience, advises the use of bare-root trees and says that, when bare-root planting is done, it is essential to have the trees in as dormant a condition as possible when dug. To force the trees into dormancy, the tops and taproot are cut and the trees are defoliated 8 to 10 days before they are dug. The taproots, he says, should be cut with sharp shears, 18 to 22 inches below the surface of the soil; the earth should then be filled back and the nursery irrigated. When the buds start to swell, 8 to 10 days later, the trees are dug, care being taken to secure as many of the lateral and fibrous roots as possible.

In humid regions such as Florida it is not necessary to employ, in order to insure dormancy, such treatments as described in the preceding paragraph, and complete defoliation is rarely practiced. Even under humid conditions, however, the budlings should be headed back rather severely (see fig. 18).

As the budlings are lifted, the roots should at once be wrapped in wet burlap, or be placed in a box in which the roots can be covered with moist moss. The root pruning preparatory to planting must be done quickly, preferably in a properly sheltered packing shed, to prevent desiccation. The roots should be kept wet while the inspection and pruning are in progress. In this pruning, all broken and injured roots are removed. The taproot is cut back to a length of 16 to 20 inches, and the larger lateral roots are shortened to the desired length (fig. 18). All cuts should be smooth, sloping cuts from the underside, to favor quick healing and the rapid development of new roots.

One of the advantages of planting bare-root trees is that, while the roots are being inspected and pruned, crooked or goosenecked taproots can be detected and the trees eliminated. No trees with malformed roots should be planted, and such defects cannot be discovered if the trees are balled. It should be noted, however, that if all seedlings showing imperfect roots are discarded when dug from the seedbed, and if the seedlings are carefully planted in the nursery, little trouble is to be expected from this cause.

### TIME OF DIGGING

The time of digging the budlings should be gauged to suit the time of planting. Nurserymen dig their trees in accordance with the time of delivery required by their customers. In California, the main digging season is from March to May; in Florida, from November to February. (For further discussion of planting problems see chap. v, below.)

Nursery trees should generally be planted as soon as possible after they are dug. The idea that the trees, whether balled or bare-rooted, should be held and "cured," as is sometimes asserted, seems to be without reason. The curing process is merely the healing that must take place after the severe pruning of both roots and tops, and this had best take place after the tree is planted, so that there will be no further shock and interruption to its growth.

### SIZES AND GRADES OF NURSERY TREES

Nursery trees are now generally sold on the basis of size, and the diameter (caliper) of the trunk, at a point 2 to 3 inches above the bud, is used as the main index of size.

In the California and Florida nursery trades the age and size grades are commonly quoted as in table 1.

TABLE 1

AGE AND SIZE GRADES OF NURSERY TREES IN CALIFORNIA AND FLORIDA

| Age of tree | California | Florida | |
|---|---|---|---|
| | Diameter (caliper) | Height | Diameter (caliper) |
| *years* | *inches* | *feet* | *inches* |
| Less than 1 | ........ | 2 to 3 | ........ |
| 1 | ½ to ¾ | 3 to 4 | ⅓ to ⅝ |
| 1 | ⅝ to ¾ | 4 to 5 | ⅝ to ¾ |
| 2 | ⅝ to ¾ | 5 to 6 | ¾ to 1 |
| 2 | ¾ to 1 | ...... | 1 to 1¼ |
| 2 | 1 and more | ...... | ........ |

The differences in price between these grades ordinarily range from $500 to $1,500 per thousand, but in times when the supply is scant the differences are greatly increased and may range from $1,000 to $2,500 per thousand. Prices, of course, are always relative, but there is little justification for paying the excessive charges last mentioned unless one is purchasing specially selected trees or trees of some rare variety.

The question of the size of nursery tree to purchase for planting is an important one and little understood by growers in general. Usually, decision is made wholly on price and on the judgment of the time that presumably will be lost if a small tree is planted. It may well be, however, that a rather small tree one year old is much better than a much larger one two years old. (See, for a full discussion, chap. ii, p. 139, on rootstocks.) The available evidence indicates that the most important selection that can be made in the nursery is the choice of the largest trees in a certain block where all have been treated alike. Certainly all markedly undersized trees should be discarded as worthless. The grower who purchases trees merely on the basis of size has no means of knowing how old the trees are or whether any elimination of undersized plants has been made. He must trust to the honesty of his nursery-

man, and it is therefore important that he should know his nurseryman and examine the nursery from which his trees are being dug. If he desires to be particularly careful, he may specify the size and age of trees desired and be present to observe the digging. Until the nursery business has so far advanced that official certification of stocks and tree selection is in operation, the grower must make use of all means available to obtain good trees, and this can only be assured by his taking pains to exercise the most careful personal inspection and supervision.

It would be good policy to pay an extra price for the privilege of selecting the largest trees in a certain block of nursery stock, but it might be a very bad policy to pay the ordinary price for merely large trees, as they might originally have been trees of subnormal size, by now grown larger from age alone. Growers should appreciate that the character of the orchard is determined in considerable degree by the kind of trees planted.

## METHODS OF GRAFTING USED WITH CITRUS

Although citrus trees are almost universally propagated by budding, other methods of propagation can sometimes be used to advantage. Grafting may be done while the trees are dormant, in January or February, or at almost any time during the growing season. If grafting has any advantage over budding, however, it is because the operation may be done while the trees are dormant. Scions should be taken from mature wood of the last season's growth, and the same care should be exercised in their selection as in the choosing of scions for budwood. Round and thornless twigs should be chosen if possible, although somewhat angular wood may be used if sufficiently mature.

### CLEFT GRAFTING

Cleft grafting is probably the simplest of all grafting methods and may sometimes be used to advantage in working over young trees that have been frozen down to the ground. It is also rather commonly used in top-working old trees, when the grafts are put into limbs of various sizes.

To perform the operation with a small tree or limb from ½ inch to 1 inch in diameter, a sharp knife is the only tool needed. Scions 4 to 5 inches long and with from three to four buds are chosen. In performing the operation, the stock to be grafted is cut or sawed off and a cleft is made in it, diametrically across the center of the stump, to a depth of about 1½ inches. The basal end of a scion is then sharpened to a wedge shape by two slanting cuts about 1¼ to 1½ inches long, on opposite sides (fig. 21, *A*). The scion is inserted in the cleft made in the stock and is pushed down into place so that the cambium layer of the scion comes in contact with that of the stock, at least on one side (fig. 21, *B*). The scion should be inserted the full length of the cut surface, the cleft being held open with the knife blade while the scion is being pushed down.

The graft is then wrapped with strips of wax cloth such as are used in budding, one or more strips being put across the top of the stock to keep the soil and moisture out of the cleft until the graft grows. In making some grafts,

especially in large stocks or limbs, string is tied around the split ends to hold the scion tightly in place, and the cracks and the cut surface are covered with grafting wax or asphalt emulsion.

If large limbs or stocks are to be split and grafts inserted, a special grafting iron and mallet may be necessary for making the cleft, and a scion may be used at each side of the cleft. If budding cloth or string is used to enclose or hold the graft in place, these must be cut in several places about a month later, after the scion is well healed on, to allow for expansion. If the graft is merely covered with grafting wax or some similar preparation, no further attention is necessary except on large limbs which may require rewaxing. As the scion grows, it is likely to require staking to protect it from wind breakage. It must also be carefully watched for some time, as suckers must be removed from the stock trunk or limb, and the developing shoot may require shaping.

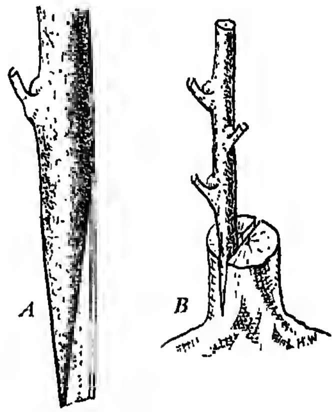


Fig. 21. Cleft grafting: *A*, base of scion showing method of cutting; *B*, insertion of scion in stump of stock.

### TONGUE OR WHIP GRAFTING

In grafting small stocks, the tongue, or whip, graft (fig. 22) is generally used. If properly made, the tongue serves to hold the scion firmly in place and forms a good union. After the scion and stock are placed together, strips of waxed cloth are firmly wrapped around the point of union, as is done with buds. The wrapping should be left on until the graft is well started, when it should be removed.

Tongue grafting is suitable for use only with comparatively small stocks, and the scion should be about the same size as the stock. This method of grafting is not likely to be of any great value in citrus propagation unless twig grafting and root grafting (described below) are later found to be feasible methods of commercial propagation.

### TWIG GRAFTING

Halma (1931) has successfully used a method of twig grafting that is probably as rapid as any method available for propagating a tree from a known stock and a known scion. Two leafy twigs of the desired stock and scion varieties are tongue-grafted together, the union is tied with raffia or budding cloth, and the graft is then treated as a cutting. The two twigs to be grafted together must be of young but mature terminal wood, such as that chosen for cuttings; the leaves are not removed (fig. 23). (Consult section on propagation by cuttings, p. 53.) Halma (1931, p. 146) states that the advantage of this method "lies in the fact that strong plants representing various combinations can be developed within one year." It is probable that this method is of value mainly in the production of experimental trees.

### ROOT GRAFTING

In the propagation of certain deciduous fruits, scions are grafted onto 4- to 6-inch sections of roots of seedlings, usually by the tongue-grafting method. These grafts are then stored, temporarily, in damp moss or sand, where the healing-on process takes place; and in early spring they are planted in the nursery.

A modification of this method has been used successfully by Halma (1927, 1931) with citrus, and there are indications that satisfactory trees may be produced in this way. Halma obtained the most satisfactory results by using twig scions 4 to 6 inches long, with 3 to 4 leaves attached. He grafted these scions to root cuttings, 4 to 6 inches long, by the tongue-graft or bark-graft method, the graft being held in place by a wrapping of raffia. The grafts were then planted in sand in a propagating bed enclosed and covered with glass so that they could be retained and grown in a saturated atmosphere—one of the essential factors in the method. Bottom heat proved beneficial but not essential.

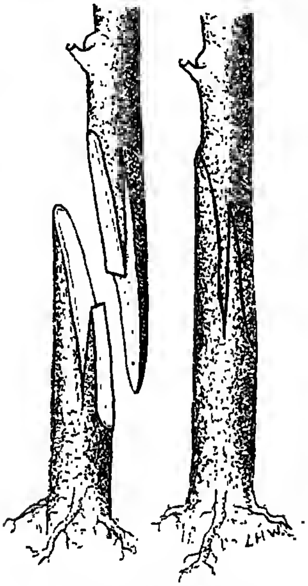


Fig. 22. Tongue grafting.

### BARK OR CROWN GRAFTING

Bark grafting is commonly used when it is desired to reproduce, quickly, tops on trees that have been killed below the bud by freezing, or in top-working old trees.

In this method the scions used are about 5 inches long, sharpened on one side by a long, sloping cut (fig. 24, *A*). Often, a similar but shorter cut is also made on the outside or outer face of the scion. If it is a frozen tree that is to be grafted, the trunk is sawed off at or near the surface of the soil, where the wood is uninjured, and several grafts are inserted on each trunk. The insertion is accomplished by loosening the bark in the concave parts of the trunk and pushing the cut end of the scions down, with the cut surface toward the wood of the trunk (fig. 24, *B*). The bark, if unbroken, will hold the scion firmly in place against the wood, and no wrapping will be required. If, however, it should be necessary to split the bark to allow the insertion of the scion, the trunk should be wrapped tightly with string or strips of waxed cloth to hold the scions firmly in place. The surface and cracks around the grafts are then covered thoroughly with some good asphalt emulsion or grafting wax, to exclude air and moisture. In recent years it has become a common practice to hold such grafts in position by nailing them to the stock with small flathead wire nails (5/8 inch long, No. 20's). With this method one nail is usually inserted through the scion near the center of the cut surface. Great care must be taken not to split or bruise

the scion (Hansen and Eggers, 1941, p. 26; and see also next page, below). Such grafts do not require wrapping, but must be thoroughly covered with wax. It is an additional safeguard to heap moist earth over the stump and to cover all but the upper buds of the scions.

When this method is used on large limbs in top-working old trees (see section on top-working, p. 60), the scions are prepared in the same way. On round limbs, it is necessary to make a short vertical slit in the bark at the end of the stub in order to push the scion down. The scions must then be held in place by nailing or by wrapping the limbs tightly with string or waxed cloth, after which all cut surfaces and openings should be thoroughly covered with some asphalt emulsion or grafting wax. In arid countries it is probably desirable to protect such grafts further by enclosing them in paper bags tied over the stub of the limb until they have healed on.

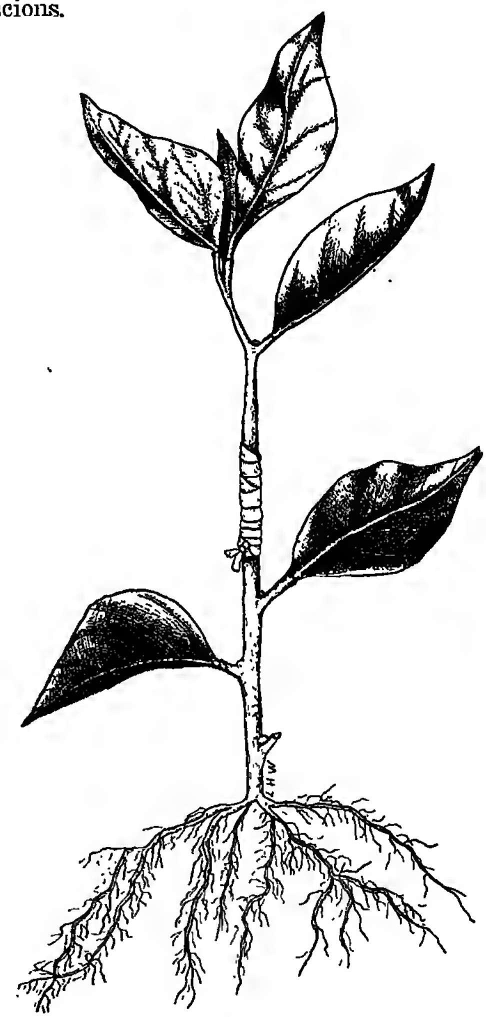


Fig. 23. A twig graft; two mature twigs are tongue-grafted together and rooted as a cutting.

SPRIG GRAFTING

In Florida this method of grafting has been used in top-working trees. It is especially suited for use in humid regions and is simple and easily operated. A scion about 4 inches long is selected (fig. 25, *A*), and the basal end is sharpened by a long, slanting cut on one side. A curved, oblique incision is made in the bark of the stock tree. The lower edge of the bark is slightly raised with the point of the knife, and the end of the scion is inserted and pushed down between the bark and the wood, in an oblique direction, until the freshly cut surface of the scion comes in contact with the growing wood cambium of the stock (fig. 25, *B*). The scion is held firmly in place by the bark of the stock and does not require ties or support. Sometimes these grafts will grow without waxing, but it is safer and better to cover the opening thoroughly with mellow

or soft grafting wax, or with some satisfactory asphalt emulsion, which will prevent evaporation and exclude rain.

Forcing the sprig graft after it has healed on is accomplished by partly girdling the limb or trunk an inch or so above the point of insertion. Forcing can also be hastened by pruning back the top. (For discussion on the removal of tops and the training of such grafts see section on top-working, p. 60.)

### INARCHING OR INARCH GRAFTING

Inarching consists in the uniting of limbs or parts of the same or different trees by a process similar to budding. Many methods of inarching are practiced, but only the method most commonly used will be described here.

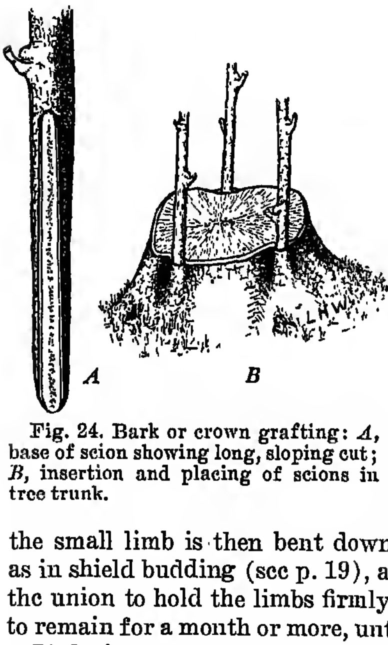



Fig. 24. Bark or crown grafting: *A*, base of scion showing long, sloping cut; *B*, insertion and placing of scions in tree trunk.

The two limbs to be inarched must be close together, naturally so placed that one may be bent over against the other. The operation is practical only where one of the limbs is comparatively small, preferably not more than ¼ inch to ½ inch in diameter. The small limb is cut off by a slanting stroke so that the cut surface will face the other limb when bent over against it at the point where the union is to be made (fig. 26, *A*). A vertical cut of the desired length is made in the bark of the large limb at the point where the two limbs can be made to touch (fig. 26, *B*). At the base of this cut a cross cut is made, so that the two cuts present the appearance of an inverted T (⊥). The end of the small limb is then bent down and pushed up into the slit (fig. 26, *C*), as in shield budding (see p. 19), and strips of waxed cloth are wound around the union to hold the limbs firmly in place. The wrapping should be allowed to remain for a month or more, until the limbs are very firmly grown together.

If the inarch is likely to be under much tension, or if it is on a large limb or trunk that is difficult to wrap, a small nail may be put through the center of the cut end of the inarched twig and driven into the trunk of the tree receiving it. This necessitates the use of a very small auger or drill with which to bore a hole through the end of the inarch, so that the nail may be inserted without splitting the end of the twig. In driving the nail into the tree when the inarch is in position, a small punch should be used, and great care should be exercised not to bruise the twig tissue. Inarches held in place in this way may be covered with a patch of waxed cloth pressed on firmly and then painted over with a thorough coating of grafting wax or a good asphalt emulsion.

Inarching is frequently used to save trees that are partly or completely girdled by foot rot, insects, mice, or gophers (fig. 27). In such cases, small seedlings, about ⅜ inch to ½ inch in diameter and balled for transplanting, are

planted at the base of the tree and inarched into the trunk above the injury. The holes to receive the inarch seedlings are dug at selected places beside the trunks of the injured trees. Two or three seedlings should be inarched into an old tree if it is completely girdled. A seedling to be inarched is placed in the hole dug for its planting, and the distance to the point where the top is to be inarched is carefully noted. The seedling is cut off as shown in figure 26, *A*. An inverted-T (⊥) cut is then made quickly in the trunk of the tree, and the inarch is slipped into place and wrapped or covered. In such inarches on old

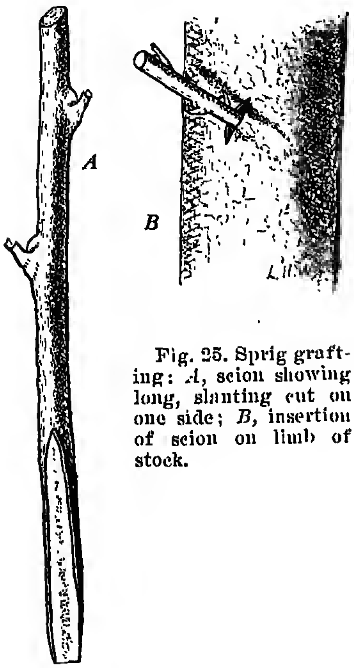



Fig. 25. Sprig grafting: *A*, scion showing long, slanting cut on one side; *B*, insertion of scion on limb of stock.

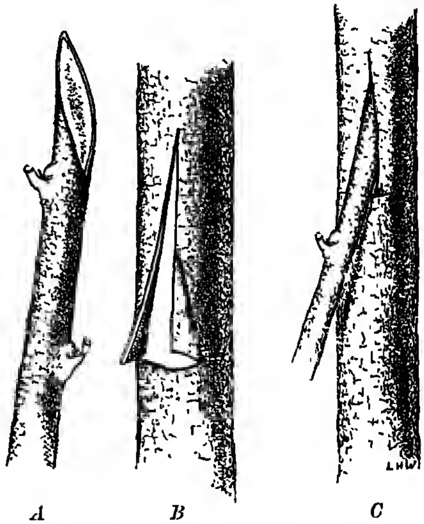



Fig. 26. Inarch grafting: *A*, top of stock seedling, showing method of cutting; *B*, bark in trunk cut to receive inarch; *C*, inarch inserted.

trees, a small nail is usually best to hold the union in place. After the inarch is in place, covered, and waxed, the soil is filled in around the balled roots, and the planting is completed.

If the injury to the treated tree is caused by gummosis, seedlings of sour orange or Sampson tangelo, which are resistant to the disease, should be used for inarching. If the injury is caused by gophers, mice, or the like, any seedlings available may be used, provided they are of good rootstock varieties.

Trees injured by partial or entire girdling, as described above, are also frequently saved by inarching sprouts that sometimes spring from the base of the trunks or from the crown roots below the injured area. The process of inarching such sprouts is the same as that employed in inarching seedlings, except that no planting is required since the sprouts are already connected with the root system. Such injured trees are also sometimes saved by bridge

grafting, which consists in connecting the roots with the uninjured trunk of the tree by using twigs that are fairly long (12 to 18 inches), which are inarched at their basal ends into roots and at their tops into the trunk.

A notable example of preservation of a diseased tree by inarching is illustrated in the saving of the original parent tree of the Washington Navel orange at Riverside, California. This famous old tree, one of the two sent from the U.S. Department of Agriculture to Mrs. Eliza Tibbets of Riverside, California, in 1873 (for history of the tree see Vol. I, pp. 530–533), was, after the death of Mr. and Mrs. Tibbets, presented to the city of Riverside. In 1902 it was transplanted to a special city park at the head of Magnolia Avenue, where for some years it grew well. In 1917, however, it was observed to be declining rapidly, and early in 1918, under the terms of a resolution passed by the Riverside city council and approved by the mayor, Dr. Horace Porter, the California Citrus Experiment Station was requested to assume the care and treatment of the tree.

Fig. 27. Tree of seedling sweet orange about eighty years old which by means of inarching some sixty years ago was saved from destruction by foot rot. Three and possibly four of the separate inarch trunks are clearly distinguishable at the base of the tree. Photographed February, 1932, in the Sutherland grove of the late L. B. Skinner near Dunedin, Florida.

A committee of the Citrus Experiment Station diagnosed the trouble as foot rot or gummosis, apparently caused or stimulated by too deep planting and the filling in of earth around the trunk in grading. The bud union was found to be ten inches or more below the soil surface. The disease had killed the bark on a band six to eight inches wide around the trunk just above the bud union.

The only way to save the tree was to supply it with a new root system, and this, it was decided, could best be done by inarching young seedlings into the live trunk wood above the girdled area. As the tree was in very poor condition, it was doubtful whether such an operation would be successful. As one kind of stock might unite more readily than another, seedlings for inarching were chosen of sour orange, sweet orange, and Rough lemon.

As the saving of this historic tree was of great importance, the responsibility was divided by having the inarches made by three men. Nine or more inarches were inserted. Of the rootstock seedlings provided, several of each kind were

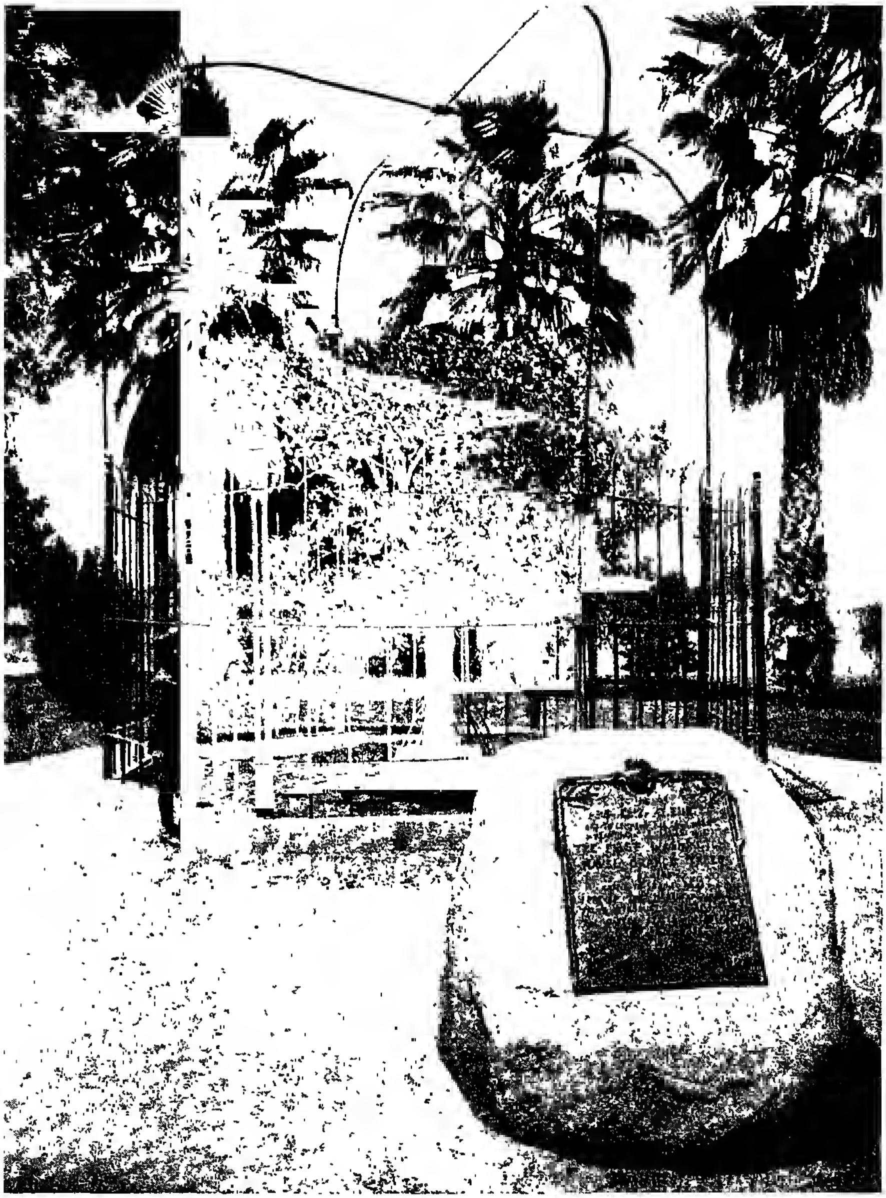


Fig. 28. Original Washington Navel orange tree in the Eliza Tibbets Memorial Park, Riverside, California, soon after the dedication of the Eliza Tibbets Monument in 1920. The inarches made about two years earlier can be seen through the fence.

The inscription on the monument reads: "To honor Mrs. Eliza Tibbets, and to commend her work in planting at Riverside in 1873 the first Washington Navel orange tree in California. Native to Bahia, Brazil. Proved the most valuable fruit introduction yet made by the United States Department of Agriculture.—1920." (Photo by courtesy of Avery Edwin Field.)

used. The inarching was performed in the spring of 1918, when the tree was found to be in the best condition for the operation (fig. 28). It was markedly successful. Almost all the inarches healed on perfectly, and soon commenced to grow and increase in girth. The tree began to show improvement and within a few months was apparently well on its way to recovery. The Experiment Station continued to care for the tree for some ten years and then returned it to the control of the City of Riverside.

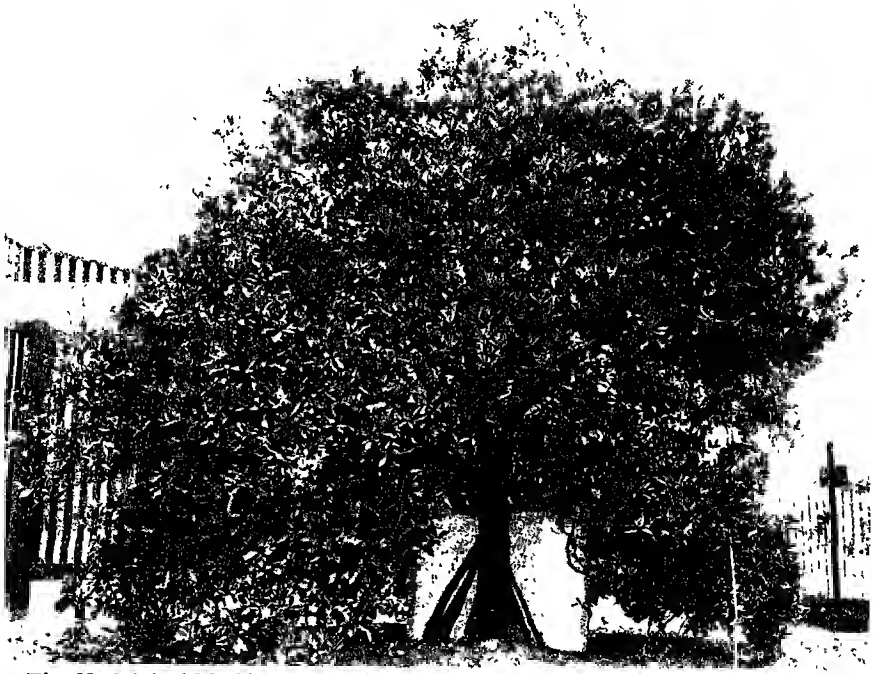


Fig. 29. Original Washington Navel orange tree in Eliza Tibbets Memorial Park, Riverside, California, twenty-six years after inarching operation. (Photographed July, 1944, by Dr. L. J. Klotz.)

Today, in 1948, thirty years after the operation, and seventy-five years after its planting, the tree is still alive and is apparently in fairly good condition (figs. 29 and 30). Although it is not a large and vigorous tree, thousands of bud sticks have been cut from it, over the years, for propagation purposes, and yet it continues to bear a fair crop of fruit annually. It has successfully withstood the vicissitudes of a long life: long journeys, two transplantings, attacks of disease, operations, several severe freezes, many severe prunings; and still continues to fulfill its function as a crop producer and as a State Monument which inspires faith in the great industry it established. Evidently, it has stamina and endurance. (For a more complete statement see Webber, 1944.)

## PROPAGATION BY LAYERS, MARCOTTS, AND CUTTINGS

Propagation by layers or cuttings has been little used in those countries in which citrus culture is most advanced, and little is therefore known concerning the possibilities of using these methods in a commercial way, or in answer to the question whether trees thus propagated are likely to make good trees that will be productive and long-lived. In South Africa, layering was for many years the principal method used in propagating citrus varieties, and in that country there are many fine old orchards in which the trees were propagated in this way (Webber, 1925). In Italy, citrons are commonly propagated from cuttings. Throughout the Asiatic tropical and subtropical regions, the propagation of citrus has usually been by "marcotts," a special type of layering. There is evidence indicating that orchard trees may possibly be grown more quickly by some of these methods than by the nursery methods now commonly practiced, as described in the preceding text. It is thus important that these methods of propagation should be understood by citrus growers, and that they be thoroughly tested as opportunity permits.

Fig. 30. Trunk base of original Washington Navel orange tree, Eliza Tibbets Memorial Park, Riverside, California, twenty-six years after inarching operation. (Photographed July, 1944, by Dr. L. J. Klotz.)

### PROPAGATION BY LAYERING

In propagation by layering, a branch or limb of a tree is caused to throw out roots at a certain point while still attached to the mother tree and nourished by it, after which it is severed from the mother and planted as an individual. The method most commonly used in the propagating of citrus in South Africa is as follows. In the early spring a suitably placed basal limb, the outer end of which bends down near the ground, is chosen for layering. The limb is bent down until it touches the soil on the lower side, and there it is cut halfway through, in a slanting upward direction, with a sharp knife. The tip end of the branch is then bent upward, and the cut end, at the bottom,

is lowered into a small excavation that has been made in the soil below it, the fresh, damp soil being packed firmly around and over it. This cut end must be buried from 5 to 10 inches under the soil and must be kept moist.

If the limb is under any tension from bending, it should be staked down so that the buried end will be held firmly in place and not dislodged or moved. If the branch is too high to be bent down easily, it may be cut half through on the upper surface and bent down at a sharp angle, but still kept attached to the parent tree so that it will receive water and sustenance until it is rooted (fig. 31). The limb buried in this way is left undisturbed during the entire

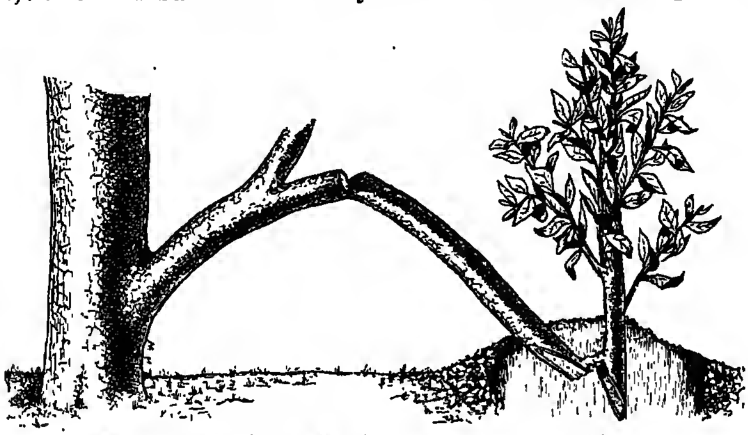


Fig. 31. Propagation by layering. Branch bent down with cut end of tip buried in soil.

season; by the end of that time it should be well rooted and growing. It may then be dug up, cut loose from the parent tree, and planted in the orchard.

This method of layering was used in the propagation of citrus by the early Dutch settlers in South Africa and has continued to be commonly used by their descendants for the propagation of superior seedlings and varieties, principally of sweet orange and mandarin. Propagation by budding as commonly pursued in other citrus sections has been introduced in recent years and is now the ordinary commercial practice, but many farmers still continue to propagate some of their trees by layering.

In Cape Province and the Transvaal, many fine old layered trees, and even orchards of layered trees that are from seventy to eighty years old, are still growing and producing large crops. A few trees, clearly grown from layers, are known to be more than a hundred years old.

Layered trees develop broad, spreading tops like budded trees, from which they can be distinguished by lack of bud unions on the trunks. They are easily distinguished from seedlings if their normal shape of top has not been changed by crowding, as the tops of seedlings are normally upright and cylindrical. The layered trees throughout South Africa usually are branched at or near the ground and can scarcely be said to have trunks, whereas seedlings, grown normally, have trunks that are simple and unbranched for several feet above

the ground. It is thus usually easy to recognize layered trees from budded trees or seedlings. It would, of course, be possible by early pruning to train a layered tree to a single trunk.

A careful comparative study of layered citrus trees in the various citrus sections of South Africa, made by the writer (Webber, 1925, pp. 39–48), has indicated that trees propagated by layering are just as good and as long-lived as trees propagated in other ways. Indeed, in comparison with budded trees on various stocks, layered trees seemed to possess rather exceptional vigor and fruiting capacity and to be equal, in this regard, with seedlings. The examination of the roots of old layered trees on several different soils showed a normal and even distribution of lateral roots such as is usually found on citrus trees, but no indication of a so-called taproot. Since taproots are rarely found on sweet orange trees under ordinary conditions of propagation, this could not be considered a definite objection to layered trees. Wherever mixed plantings of layered and budded trees were found, the owners, in general, considered the layered trees to be the more vigorous, productive, and healthful of the two.

The plants that have been propagated by layering are mostly selected sweet seedling oranges and selected seedling mandarins of the general type of the Dancy tangerine. Whether comparable results would be obtained by similar propagation of such standard varieties as the Valencia and the Washington Navel orange is not surely known. A small grove of ten-year-old Washington Navels on Caxton Farm, near Grahamstown, Cape Province, propagated by layering, compared very favorably with trees of the same variety and age budded on Rough lemon stocks. The Washington Navel is a rather weak, slow-growing tree, and if this variety succeeds from layers, growing thus on its own roots, strong vigorous varieties such as the Valencia or Du Roi should do well.

It may be concluded that layering can safely be used wherever it is the most convenient method of propagation and where the varietal susceptibility to gummosis and root rots is not a serious menace. It cannot, however, be considered a satisfactory method for general nursery use, because it is not adapted to the rapid propagation of large numbers. Furthermore, it would permit of no opportunity for the effective practice of bud selection, and this is a serious drawback with unstable sporting varieties such as the Washington Navel, Valencia, and other valuable citrus types.

### RING METHOD OF LAYERING

Oppenheim (1927 and 1932) has described the successful use of the ring method of obtaining a number of rooted layers from the same seedling. A year-old seedling is cut back in early spring to a height of about 8 inches. A number of new branches develop on the trunk thus cut back, and in about six weeks, when these have matured enough to become hardened and rounded, about two-thirds of those on the lower part of the trunk are prepared for rooting. The preparation consists in tying three or four circles of thin copper wire in a ring around each stem, at a point about 2½ inches from the seedling trunk.

Earth is then heaped up around the seedling to a height of 4 to 6 inches above the highest ring. The branches on the upper part of the seedling are left unringed, to supply the normal nutrition to the roots. The mound of earth covering the ringed branches must be kept moist until the rooting has taken place, a process which requires from 3 to 4 months. When the ringed branches are well rooted, they may be severed from the parent seedling and transplanted to the nursery.

This method of layering may prove valuable in developing clonal progenies of different seedlings, particularly for experimental purposes.

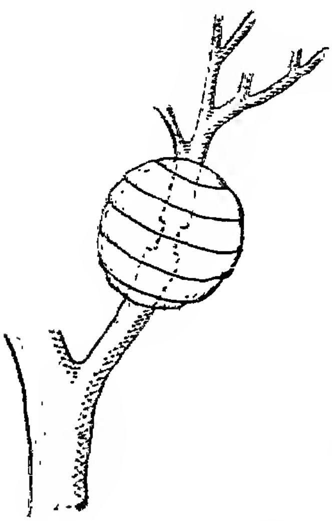


Fig. 32. Method of marcottage.

PROPAGATION BY MARCOTTAGE

In subtropical Asia the propagation of citrus and other plants is accomplished most commonly by a type of layering known as marcottage or marcotts. In general, this method consists in the selection of a conveniently placed twig or small branch which, at a point 1 to 1½ feet from the tip, is girdled by the removal of a strip of bark about ½ inch wide, or is tongued by an upward cut, with a small splint of wood placed in the cleft to hold it slightly apart. The twig, at the point girdled or tongued, is then immediately covered and encased in a ball of moist clay, moss, or coconut fiber, held in place by cloth or burlap, tightly wrapped and tied around it (fig. 32).

Hunter (1932*a* and 1932*b*), in Trinidad, obtained the best results by using moss covered with rubber tubing. He also found that it did not greatly matter whether ¼-inch twigs of the last growth cycle, or 1-inch limbs of older growth, were used. The position of the girdled ring in relation to the buds was also found to be immaterial.

The ball is commonly made about 4 to 5 inches in diameter. If a ball of this size is too heavy to be supported by the twig, it must be supported by attaching it to larger limbs or to stakes driven into the ground. The ball must be kept moist by frequent wetting or by water slowly dripping on it from some container supported in the tree. In 1½ to 2 months, or more, the length of time depending upon environmental conditions and upon the variety, roots will be thrown out from the base of the twig, above the girdled strip, into the moist soil of the ball. The marcott can then be cut loose from the parent tree and planted in soil without removing the ball. It is usually best to prune the top back somewhat and to remove part of the foliage, as the root system developed in the ball is not likely to be large enough to support the entire top of the branch.

The writer saw this method in practical operation in the propagation of citrus varieties in Ceylon and in Java, and it has been commonly used in the

Philippines (Wester, 1913). It is especially adapted for use in moist, humid regions and would doubtless require special care to insure its success in arid regions.

## PROPAGATION BY CUTTINGS

In view of the very general use of cuttings or slips in the propagation of numerous cultivated plants, such as figs and olives, it is frequently asked why this method is not successful with citrus. The general impression among growers in the United States has been that citrus cuttings were difficult and impractical to root, and that trees grown from cuttings were unsatisfactory. Experiments conducted in recent years have shown, however, that almost all species of citrus can be successfully rooted as cuttings, although some species and varieties are much easier to root than others. Swingle, Robinson, and May (1924) obtained satisfactory results in rooting cuttings of the shaddock, citron, lemon, mandarin, orange, citrange, and various citrus relatives; and satisfactory results have also been obtained by Halma (1926*a*, 1926*b*, 1931) and by Hunter (1932*a*, 1932*b*).

*Methods used in propagation of cuttings.*—The methods that have proved most satisfactory in preparing citrus cuttings differ but little from the methods used with other plants. Citrus cuttings are preferably taken from young twigs of mature terminal growth. It is important that they be taken from vigorous, healthy trees and that all the leaves on the twigs be mature, healthy, and free from injury. Only the terminal shoots should be used; but these shoots are frequently long enough to permit of being divided into two cuttings, each 4 to 6 inches long.

The best results are obtained by leaving three or four leaves on the apex of each cutting and removing only two or three of the leaves from the basal end. The removal of all the leaves, or even the partial cutting of those left, retards the rooting and growth. After removal from the tree, the cuttings should be kept continuously moist, so that no wilting takes place. Before the cuttings are planted in the rooting soil, the base of each is cut off with a sharp knife, usually at a point just below a node. Thus prepared, the cuttings are ready to plant. Halma (1931, p. 133) states that "whether the basal cut is made immediately below a bud or above is not important." He also found that there was apparently a relation between the slope of the cut and the number of roots formed: "the greater the slope the fewer the number of roots produced." The basal cuts, then, should apparently be made nearly at right angles to the longitudinal axis of the twig.

The best results in rooting have been obtained in greenhouses, where rooting beds can be provided with bottom heat from steampipes or from electric heaters controlled by automatic regulators, and where the bed itself is enclosed and covered with sash so that the tops of the cuttings can be retained in a moist atmosphere to prevent wilting. The rooting beds are filled to a depth of 6 or 8 inches with a fairly coarse, clean sand, into which the bases of the cuttings are plunged to a depth of 3 to 4 inches. For the best results the soil temperature should be kept between 75° and 90° F., and the air temperature from 60° to 80° F. If such temperatures can be maintained, and if the atmos-

phere surrounding the cuttings can be kept constantly at a sufficiently high humidity to prevent wilting, the cuttings scarcely seem to stop growing and will develop an abundant root system in a month or six weeks; they can then be lifted and transplanted to the nursery or bed in a lath house.

Halma (1926*a*) was able to root cuttings of most species without the use of bottom heat, but the time required was usually longer and the proportion of loss larger. Swingle, Robinson, and May (1924) devised a solar-heated propagating frame with which fairly good results were obtained. An apparatus of this kind can easily be constructed by any handy man. Hunter (1931) used a similarly constructed solar heater with success. Rooting in hotbeds where the bottom heat was derived from a deep bed of manure was also tested by Hunter, but the results were not very satisfactory.

The ringed-hardwood-cutting method, found by Hunter (1932*a*) to be most successful if hardwood cuttings are to be used, is a slight variation of the method described above. Mature twigs, the bark of which has become russeted, are girdled by removing a half inch ring of bark. The twigs are left attached to the tree without any other treatment or covering for about 20 days, until a visible callus has formed on the upper or outer circle of the cut bark. They are then severed from the mother plant, care being taken not to injure the callus; next, the twig and foliage are pruned back to the desired extent on each cutting, which is then planted in a propagation chamber such as is used with other cuttings. In Hunter's experiments the twigs used were cut back to about 12 inches in length, and 5 to 7 leaves were left at the top of each. Such cuttings were found to root more quickly and more abundantly than unringed cuttings. It does not seem probable that this method of propagation will prove successful in an arid country like California, but it may be valuable in countries of high humidity.

Halma (1931) had some difficulty in handling rooted cuttings transplanted into pots, owing to the development of curled and tangled roots, which injured the tree in later growth. He found it much more satisfactory to transplant the cuttings direct to the nursery. This can be done 2 or 3 months after starting the cuttings, when they have developed a fairly extensive root system. Before the cuttings are transplanted, they must be hardened by a gradual lowering of the humidity until they become adapted to the normal air conditions. The plants can then be lifted and prepared for planting by the removal of the new growth of the top, the older original leaves being retained. They are then planted bare-root in the nursery row.

Well-rooted cuttings, carefully handled and kept continuously moist, may be transplanted to the nursery successfully in hot dry weather if they are immediately watered and shaded. Shading is commonly provided by one or two shingles stuck in the ground in such a way that the plant is protected from the direct rays of the sun during the middle of the day.

Lemon cuttings grown in the nursery generally reach the size of salable budded trees in about two years; sweet orange and grapefruit, in two or three years. If such cuttings are to be used as rootstocks, they can be grown to suitable size for budding in one year.

*Ease of rooting in cuttings of different species.*—There is a marked difference in the quickness and ease with which cuttings of different species may be rooted. With cuttings that were grown in a solar propagator with bottom heat, Hunter (1932*a*, p. 138) found periods from date of setting to first rooting to be approximately as follows:

| *Species or variety* | *Period (days)* | *Species or variety* | *Period (days)* |
|---|---|---|---|
| Citron | 10–15 | *Citrus excelsa* (?) | 25 |
| Trinidad lime | 10–15 | *Citrus hystrix* | 30 |
| Rangpur lime | 15–35 | Sour orange | 30 |
| Kusaie lime | 15–35 | Shaddock | 35 |
| West Indian lime | 15–35 | *Citrus nobilis* (now *C. reticulata*) | 250 |

Comparable differences between various species were also found by Halma (1926*a*).

Halma (1931, p. 136) gives the following data on the percentage of rooted cuttings obtained with the common citrus species when grown in a special propagation bench with bottom heat.

| | |
|---|---|
| Citron (*Citrus Medica* Linn.) | 100 per cent |
| Lemon (*Citrus limonia* Osbeck; now *C. Limon*) | 98 per cent |
| Sour orange (*Citrus Aurantium* Linn.) | 92 per cent |
| Sweet orange (*Citrus sinensis* [Linn.] Osbeck) | 85 per cent |
| Grapefruit (*Citrus grandis* [Linn.] Osbeck) | 75 per cent |
| Mandarin orange (*Citrus nobilis* Lour. var. *deliciosa* Swingle; now *C. reticulata*) | 75 per cent |

It is evident from the experiments of these investigators that citrons, limes, and lemons root most quickly and readily, and that sour orange, sweet orange, grapefruit, and mandarin oranges are slower and more difficult to root. Such slow-growing varieties as the Satsuma (*C. reticulata* var. *unshiu*) are perhaps the slowest and most difficult to root.

Halma (1929; 1931, p. 156) found that there is apparently a close relation between the degree of development of the leaf palisade tissue for each species and its ability to root from cuttings. Thus the citron and lemon, with the highest percentage of palisade tissue, root the most easily, while the Satsuma, with the lowest percentage, is difficult to root.

*Healing and rooting processes in cuttings.*—According to the studies of Priestley and Swingle (1929) on the cellular development in the growth of cuttings, the cells on the freshly cut surface of the cutting that are not actually mutilated and killed are somewhat strained and their permeability is increased. A liquid containing solutes and fatty substances is released from the cells and accumulates in the intercellular spaces and on the surface. If a sufficient amount of air is present, these substances undergo a rapid chemical change and are deposited as suberin in the cell walls and on the surface, a varnish-like film thus being formed. This suberin film serves to protect the tissue from invasion by microörganisms and injury by excessive evaporation. Suberization takes place most readily in a saturated atmosphere and in the

presence of thorough aeration. If the cut surface is kept wet, the fatty substances are leached away and suberization is prevented. Thus, cuttings kept too wet will not form a suberin layer and are likely to rot.

After the formation of the suberin layer, and underneath it, layers of callus tissue, or cork, are formed through cell multiplication. The walls of these new cells contain suberized lamellae, or layers. This tissue is thus an effective protection against fungus infection and rapid drying out. After the callus development is completed, the new roots soon begin to form. These originate in the wood cambium and grow outward through the callus tissue.

*Advantages and disadvantages in use of cuttings.*—It is evident from the results outlined above that large numbers of cuttings could readily be made of most species of citrus, if conditions were found to justify or necessitate their use. It is still doubtful, however, whether trees so propagated will be as satisfactory and long-lived as those of the same varieties propagated on well-adapted seedling rootstocks. A small number of orange and lemon varieties propagated by cuttings and grown in California have come under the writer's observation from time to time, but the number has been too limited and the comparisons too doubtful to justify any conclusion concerning their comparative value.

Halma has stated:[1] "Citrus trees may be propagated by other means such as cuttings, layers, and grafting, but it is doubtful if any other method than budding on seedlings will be used for commercial propagation in California in the near future. While lemon cuttings root readily, trees now thirteen years old are not as productive and, in the case of the weaker types of the Eureka variety, are less vigorous than budded trees on sweet orange and grapefruit rootstock. Similar aged Navel and Valencia orange trees, on the other hand, have proved to be as productive and vigorous as budded trees on sweet orange rootstock, but unless they eventually show marked superiority over budded trees, the expense for special equipment and special care needed to root the cuttings is not warranted." This statement is based on experimental evidence and is probably the most reliable opinion now available.

Physiologically, layers, marcotts, and cuttings represent the same general method of propagation, the only difference being that layers and marcotts are branches that by manipulation are caused to strike root while still attached to the mother tree, whereas cuttings are smaller twigs rooted after detachment from the parent tree. If, then, good trees of citrus are produced by any one of these methods, the others, it would seem, may be expected to give like results. The extensive and successful use of layers in South Africa (Webber, 1925; and this volume, p. 51), and the extensive use of marcotts in India, Ceylon, Java, and other Asiatic countries, indicate strongly that good trees may be produced by these methods of propagation. It may also be mentioned that in Mediterranean countries the citron is most commonly propagated by cuttings, and that citron growing is an important industry there.

Experience seems to indicate that nursery trees of the size ordinarily

[1] Dr. F. F. Halma, University of California, Los Angeles, in letter of July 17, 1944, to the writer. Quoted with permission.

required for orchard planting can often be produced from cuttings in about one year less than trees of similar size can be produced by growing rootstock seedlings and then budding them.

Even if cuttings under certain conditions produce as good trees as the same variety budded on satisfactory stocks (which they probably do), there are nevertheless several important advantages to be obtained by using budded trees. The principal of these are that rootstock varieties may be chosen that are (1) resistant to such diseases as gummosis, root rots, tristeza, mal secco, and the like; (2) better adapted to certain types of soil than the fruit variety; and (3) more vigorous than the fruit variety and thus stimulate a more vigorous growth. A serious disadvantage in using cuttings or layers for extensive commercial propagation is that each tree grown requires from at least five to a large number of buds, which greatly increases the difficulty and cost where it is desirable, as with citrus, to take propagating wood from carefully selected, disease-free mother trees.

The uniformity of cuttings taken from the same mother tree has been assumed to be a character in favor of their use, especially in propagating rootstocks. Cuttings do of course produce trees of the same variety as the mother tree from which they are taken, but they exhibit variations in rate of growth, as indicated by size, about the same as similar budded trees on different seedling rootstocks (Halma, 1933 and 1941).

Seedlings for rootstocks are much easier to grow than cuttings, and the seedlings of such highly nucellar embryonic rootstocks as the Rough lemon, Palestine sweet lime, Sampson tangelo, and various citranges reproduce remarkably true to type through seed propagation (Webber, 1932, p. 12; and this volume, pp. 138 and 146–147). Seedlings of sour orange, sweet orange, and grapefruit, when intended for rootstocks also, may be reduced to almost a uniform type by careful roguing, so that little is to be gained in uniformity by using cuttings.

In view of the foregoing, it is the writer's judgment that the now common practice of using budded trees in commercial citrus propagation is the most desirable method and that it will gradually become the dominant method in all countries. The employment of cuttings, layers, and marcotts, however, has a place in experimental work, and occasionally when facilities for budding propagation may not be available.

### THE NURSE-GRAFTED Y-CUTTING METHOD

An ingenious method of obtaining cuttings of plants that are difficult to root was described by Swingle, Robinson, and May (1929) as the "nurse-grafted Y-cutting method." By this method one limb of a Y-shaped branch of the plant which is to be propagated is approach-grafted or inarched with a small nurse plant, a seedling, or a rooted cutting, of a suitable stock type, the roots of which are held in a marcottage ball, box, or soil pot (fig. 33). The ball or pot must be supported and must be kept continuously moist. In about two weeks the graft will have fused, and the base of the Y-branch is then girdled by removing a ring of bark about ⅛ inch to ¼ inch wide (fig.

33, *c*). This causes the accumulation of reserve food material above the ring, which favors the production of roots when the Y-cutting is eventually planted.

In about four to eight weeks after the healing of the graft is complete the Y-branch is cut through at the ring (fig. 33, *c*), the Y-cutting with its nurse plant thus being severed from the original mother plant. The roots of the nurse plant are then freed from the soil pot or marcottage ball, and the nurse plant with the attached Y-cutting is planted (fig. 34) in a suitable propagating bed having bottom heat. The top of the nurse plant should be cut back


Fig. 33. The nurse-grafted Y-cutting method: *a*, branch chosen for Y-cutting; *b*, nurse-plant seedling (usually a pot must be set on a stool for support); *c*, point girdled to form callus where branch will finally be severed.

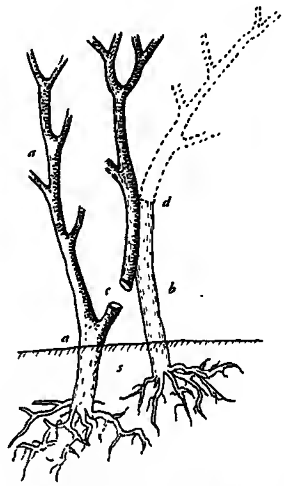



Fig. 34. The nurse-grafted Y-cutting method: *a*, Y-cutting; *b*, nurse-plant seedling; *c*, point where rooted cutting is severed from branch of cutting grafted into nurse plant; *d*, point where top of nurse plant is cut off; *s*, soil of propagating bed.

at this time to a few inches above the graft union (fig. 34, *d*). Soon the Y-cutting will throw out roots. At the end of about a month in the propagating bed it may be separated from the nurse plant by a gradually deepened notch cut in the base of that branch of the Y-cutting which was grafted (fig. 34, *c*). This notch is deepened every few days until the rooted cutting is finally severed from the nurse plant.

Two separate plants are thus produced, one a rooted cutting (on its own roots) of the plant which it was desired to propagate, and the other a grafted plant consisting of a scion of the mother plant, propagated on the root of the nurse plant. By this method its authors have rooted the most difficult species and relatives of citrus as cuttings.

USE OF HORMONES IN ROOTING CUTTINGS

In the last decade much has been written concerning the use of hormones or auxins to stimulate the rooting of cuttings. With citrus, promising results have been obtained, but the use of these substances is still in the experimental stage. Cooper (1936, p. 785) stated that "by soaking the base of lemon or rose cuttings in hetero-auxin [indole-3-acetic acid] solution of relatively high concentration (0.5 mg. per cc. of water) for eight hours before setting in sand, a much greater number of roots was induced on the treated than on the control cuttings."

In further experiments, Cooper (1940) and Cooper and Knowlton (1940) made tests with several different kinds of citrus. The basal ends of the cuttings were soaked in a standard 0.02 per cent aqueous solution of indoleacetic acid for 24 hours. The cuttings used were from mature terminal growth, preferably round, cut to 4¾ inches in length, with two full-sized leaves left at the apex of each. In these experiments the percentage of rooting, and the average number of roots per cutting, were markedly increased with Rough lemon, Morton citrange, Conner grapefruit, Marsh grapefruit, sour orange, Homosassa sweet orange, Bergamot orange, Suen Kat mandarin, and Cleopatra mandarin. With the Woglum lime, the Rangpur lime, the Villafranca lemon, and the Hongkong kumquat, however, the percentage of rooting was not increased, but the average number of roots per cutting was much increased.

Pearse (1939, p. 49) quotes Hubert and Beke (1938) as having obtained an increased percentage of rooting with cuttings of the sweet orange (*Citrus sinensis*) by experimental treatments with indoleacetic acid, 100 mg. per liter, for 8 hours.

Biale and Halma (1938) conducted experiments in the use of heteroauxin (indole-3-acetic acid) in various strengths with leafy-stem cuttings of all the principal varieties of citrus grown in California. In describing one series of experiments, these authors stated (1938, p. 445): "While treated grapefruit and Valencia showed marked increase in percentage of rooted plants over the check, the lemon and citron rooted just as well without treatment. However, the number of roots was considerably greater on the treated than on the check. The number of roots also increased with increase in concentration. Poor results were obtained with Dancy tangerine, and the kumquat was a complete failure."

In a more extensive series of experiments reported in the same paper by Biale and Halma (1938) the results of the treatments were much less favorable; the percentage of rooting showed little if any increase. The authors stated, in conclusion: "The chief effect of heteroauxin manifests itself in an increase in number of roots, but this effect is much more evident in species which root readily [without treatment]."

The effect of auxins on the rooting of cuttings of sour orange (*laranjeire azêda*) have been reported by De Almeida (1938, 1940), in Portugal. Cuttings were taken from soft, semiwoody, and woody growth, and different batches of 50 cuttings each were treated for 24 hours in two standard strengths (1 : 10,000

and 1:20,000) of indoleacetic acid and naphthaleneacetic acid. They were then planted in the greenhouse, with bottom heat and temperatures controlled. The soft, herbaceous cuttings failed in all trials. The best results were obtained with semiwoody cuttings treated with the strong indoleacetic acid (1:10,000), where a rooting of 78 per cent was recorded, in comparison with 12 per cent for the checks treated with water only. The highest rooting obtained with naphthaleneacetic acid (54 per cent) was with the weak solution (1:20,000). Woody cuttings in all trials gave lowest percentages of rooting, those treated with indoleacetic acid (1:10,000) giving only 28 per cent.

Many growth-promoting auxins, such as indoleacetic acid, indolebutyric acid, naphthaleneacetic acid, and others, have apparently given marked reactions with some plants in stimulating rooting (Went and Thimann, 1937; Traub, 1938). The evidence available on citrus is somewhat contradictory, however, and does not yet clearly indicate the practical value of such treatments in stimulating the rooting of cuttings.

## TOP-WORKING OF CITRUS TREES

### WHY TOP-WORK CITRUS TREES?

Occasionally it becomes desirable to change the variety of a tree, or perhaps of an entire orchard. No matter how much care is given to bud selection, sometimes a bud stick of a poor strain or variety is used, or a mixture occurs accidentally and is not discovered until the trees fruit. As soon as such off-type trees are discovered, they should be rebudded or top-worked to a good variety. It also may happen that the market demand changes and creates conditions which make a change of the variety of a grove desirable. Such groves may be successfully worked over to the variety desired, if the stock and the original scion trunk are such that a congenial combination will be provided for the new scion variety.

Top-working old trees and old orchards, however, is an expensive and frequently doubtful procedure. Experience has shown that many old orchards which have been top-worked should have been pulled and the land planted with young trees. The presence of diseases, especially virus diseases that may escape detection, could result in a poor orchard and perhaps considerable loss. Esselen (1933) wrote: "Only in cases where the trees are normal in all respects, except in that they produce undesirable fruit . . . can top-working be expected to be successful." No undersized or diseased trees should ever be top-worked. Orchards that are apparently vigorous and healthy should not be top-worked until all the trees have been thoroughly inspected to discover the possible presence and prevalence of such virus diseases as scaly bark. If the number of trees to be treated is at all great, growers are urged to seek the best expert advice before deciding on the policy to pursue.

### TREES THAT CAN BE TOP-WORKED

Little information is available from which to judge what combinations of stocks and scions in top-working are likely to be most successful. It can be stated that, in general, any citrus trees may be top-worked with any variety

of the same species, with reasonable expectation that growth will be equal to that of the original tree. That is, a top of sweet orange may be top-worked to any other sweet orange, a lemon to any other lemon, or a grapefruit to any other grapefruit, with expectation that the combination will be equally successful if the original tree was on a congenial stock. It must be understood, however, that top-working means that the combination produced will consist of rootstock, interstock, and top, and that each of these may be different species or different varieties. Each of these parts of the top-worked tree will exercise an influence on the growth of the combination, and it is thus of primary importance to know that the combination is likely to produce satisfactory results.

It is apparently important that the rootstock of the original tree should be one that is known to be satisfactory for the new top variety to be added. How far an intermediate sector of the trunk (interstock) of a certain variety, such as is left in top-working, affects the combination, or can be expected to overcome a lack of congeniality between rootstock and top-worked variety, is not yet entirely clear. Some results which have been observed seem to indicate that a sweet orange interstock between lemon varieties and sour orange rootstocks tends to overcome in part the lack of congeniality commonly exhibited between these two species. It seems probable from certain observations that interstocks of two different varieties of the same species may, at least occasionally, react differently. (For discussion of interstock reactions consult section on interstocks, chap. ii, p. 152.)

## METHODS OF TOP-WORKING

The eye- or shield-budding method of top-working citrus trees[1] is the most satisfactory of those with which the writer is familiar. When this method is used, the budding is done preferably in the early part of October, while the bark is still slipping and there is time for the healing of the buds to take place before cold weather begins. Each tree that is to be top-worked presents an individual problem, if the buds are to be placed properly to provide for the development of a strong, well-shaped top.

In preparing the tree for budding, only such pruning should be done as is necessary to open up the top and permit the operator to work freely. Too much pruning is likely to slow up growth and set the bark so that the budding will be delayed for some time, until growth is resumed. Such delay may make the budding too late. Such pruning as is found necessary should be done just before the budding.

On each tree, the 3 to 6 limbs which are the best placed to give a properly spaced top are chosen for budding (fig. 35). A widespreading top soon forms from the buds, and the budded limbs may therefore be rather close together. The limbs selected may be 2 to 4 inches or more in diameter, but preferably not more than 4 inches. At points where buds are to be inserted, the limbs should be as nearly upright as possible, so that the erect-growing shoots from the buds will not form too sharp an angle with the supporting limb.

[1] The method is described here as practiced by C. S. Knowlton of Fullerton, California, an expert worker in this field.

For top-working, good-sized, round budwood, about 3/8 inch in diameter, should be chosen. The ordinary shield- or eye-budding method is used, as previously described (see section on inserting and wrapping the buds, p. 19). On each limb that is to be worked over it is usually desirable to place two buds; one alone might fail to grow, but with two the chances of success are more nearly assured. The buds should be placed on the same side of the limb, an inch or so apart and 12 to 18 inches from the central trunk. If the limb is a lateral one and not entirely erect, the buds should, preferably, be placed on the upper side of the limb, each slightly at one side of the upper center (fig. 36).

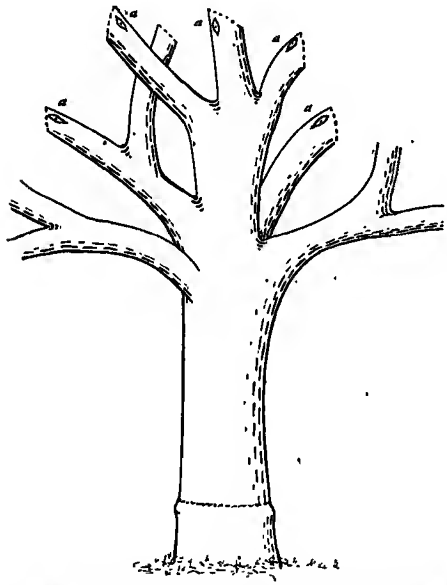



Fig. 35. Sketch illustrating choice of limbs to be budded in top-working old trees, and location of cuts in removing the limbs to force the buds; *a*, *a*, buds.

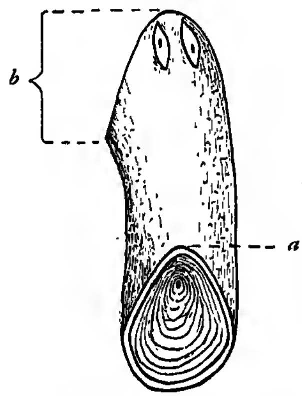



Fig. 36. Sketch illustrating proper location of two buds at right and left of center of cut-off end of a lateral limb, in top-working old trees. *a*, upper surface of limb; *b*, where limb is cut off to force buds.

When old limbs are budded by this method, the bark must be thinned slightly, to prevent too great pressure on the bud and to allow the bark of the trunk to fold in more closely around the bud with less air space. The thinning is done either by carefully slashing the bark up or down with a sharp knife and removing thin shavings, or by scraping. After the bark has been thinned, a **T**-shaped cut is made in the center of the small thinned area and the bud is inserted by pushing it downward into the cut.

The bud is wrapped in the usual way, by winding it with strips of waxed cloth drawn tightly around the limb. If the two buds have been inserted properly at the same height on the limb, both can be covered by the same wrapping. The buds are then left for about four to six weeks, until they are well healed

on, after which the wraps should be removed. If the wraps are left on too long, the callus forming on the edges of the old bark may grow in and entirely cover the bud and prevent its growth.

After the buds are unwrapped, no further attention is necessary until sometime in January, when the limbs should be cut off just above the buds. This will stimulate the buds to develop when growth first starts in the spring. The limbs should be sawed off carefully, with a sloping cut, in such a way that the buds are left at the upper edge of the cut, so near to the cut edge that, as they grow, they continue the branch without leaving a protruding stub (fig. 35). The cut can start about 1/4 inch above the upper end of the bud, or at about the point above the bud where the top of the T-cut was made in inserting the bud. As soon as the limb is removed, the cut surface should be thoroughly covered with a good asphalt emulsion or with grafting wax.

While the covering wax is still soft, it is a good practice, also, to cut a close-fitting cap of good white paper of the same shape and size as the cut surface of the limb and to place this cap over the cut end and press it into close contact with the wax to hold it in place. This white covering reflects heat and serves as an additional protection. Care should be exercised not to let the covering wax run down over the buds. All permanent main and lateral branches should be thoroughly whitewashed to prevent sunburn. (For a whitewash formula see Appendix to chap. v, p. 299.)

The buds should push very early in the spring and make a vigorous growth. Attention must be given them from time to time, to direct the growth and remove from the old limbs all vertical sprouts that may interfere with the growth of the buds. It is also desirable, if the buds tend to grow too tall and slender without branching, as they sometimes do, to nip the tops off to stimulate branching before they get too high. If both buds inserted on a limb have grown, one should usually be removed, the one that is the larger and better-placed being retained. Ordinarily, if the buds are properly spaced no staking or tying is necessary; but if wind breakage is feared, they may be supported temporarily by loose ties from one bud to the other, or by staking.

The limbs that were not budded, if placed where they do not interfere with the growing buds, should be left temporarily as nurse limbs to keep the tree and roots in good condition while the buds are growing.

For further pruning of the top-worked trees, Mr. Knowlton (see footnote, p. 61) described the procedure as follows: "I usually start light pruning on the nurse limbs shortly after the buds have started nicely. I first cut off most of the growth that is higher than the buds and then the growth that drags on the ground. This may well be roughly done with large, long-handled pruning shears. All vigorous suckers should be removed, to keep them from getting out of control, so that the vertical growth will go into the buds.

"The final removal of the nurse limbs should be started in the winter following the forcing of the buds, and all should be removed during the following summer. If any vertical limbs were left unbudded these should be the first removed. Trunks and large limbs that remain should be whitewashed promptly [fig. 37], to prevent serious sunburning."

The removal of the tops from the budded limbs and the removal of the nurse limbs, at the proper time, is likely to destroy an amount of fruit that the grower would like to save. Experience has shown, however, that no attempt should be made to salvage anything from the fruit on trees that are being top-worked. For successful top-working, each operation in the process of pruning must be done at a certain time, regardless of the fruit, which, at best, is of little value or the trees would not have been top-worked.

If both of the buds on a limb fail to take, the limb should be cut off in January when the other limbs are removed; it can then be rebudded early in the spring when the bark begins to slip. In rebudding, the buds are placed close to the cut end of the branch, in about the same position as before with reference to the cut end, so that the limb will not have to be stubbed back later (fig. 35). Although fall budding, as described above, is the preferable method, it is entirely feasible to cut off the chosen limbs in January and do all the budding in the spring.

Fig. 37. Group of top-worked sixty-year-old sweet seedling orange trees, after removal of nurse limbs and whitewashing of trunks.

Another method of top-working commonly used is to place buds in selected limbs in the spring and, after they have healed on, cut off the limbs to force growth; otherwise, this method is the same as the preceding. It is not so satisfactory a method, however, as the main growth of spring is lost, and the bud sprouts go into the succeeding winter soft and immature.

Still another method, at one time commonly used, is to cut off the limbs where desired and allow sprouts to grow from them, into which buds are inserted, as in budding nursery trees. This method has been almost wholly abandoned; it consumes too much time and is too severe a shock to the tree because of the two different and severe prunings required.

In top-working old trees, many forms of sprig, bark, and cleft grafting (see figs. 21, 24, and 25) have also been employed successfully. In applying these methods in top-working, the same general procedure is followed as when

budding is used. The limbs to be top-worked are chosen in the same way, but bark and cleft grafting require that these be cut off when the grafts are inserted. The operation is usually performed in the spring soon after the bark begins to slip. The subsequent care in the development and protection of the growing scions, and the pruning off of the unworked limbs, is the same as with the budding method. Some operators, apparently, still prefer to use grafting methods in top-working old trees, but experience seems to have indicated that none of these methods are, in general, as satisfactory with citrus as the shield- or eye-budding method described above.

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## Chapter II

# ROOTSTOCKS: THEIR CHARACTER AND REACTIONS

BY

HERBERT JOHN WEBBER

The varieties of citrus fruits grown commercially do not reproduce true to type through seed. They must therefore be propagated by some vegetative means, such as by cuttings or layers, or by grafting or budding onto a rootstock of some nearly related species or type. The last-named method is the one generally used in the propagation of citrus varieties, and the common nursery practices are described in the preceding chapter.

The propagation of different types of citrus by grafting has been practiced to some extent since the early days of the Christian Era. Palladius, who is thought to have written at some time in the fifth century, stated (Gallesio, 1811, p. 215): "They graft the citron in April in warm districts and in May in colder latitudes, placing the graft not upon the bark, but opening the stem or trunk near the ground."

*It has long been recognized that the stock and the scion have an important* reciprocal influence on each other, and that a certain affinity or congenial relationship must exist between them. It is also recognized that different stocks vary in their adaptability to growth on different soils and under different climatic conditions, as well as with different scion varieties. While a considerable fund of information has been accumulated concerning reactions under different conditions, growers in many citrus sections are yet somewhat in doubt about the best stocks to use.

## DEGREE OF AFFINITY OR CONGENIALITY OF ROOTSTOCK AND SCION

Not all citrus species and types can be used successfully as rootstocks. Even though it may be possible to work or unite one species with another, the growth resulting from the union may not be commercially satisfactory. The stock and scion must not only be capable of uniting, but must also be capable of producing long-lived, productive trees. This relationship between stock and scion, which is commonly termed affinity or congeniality, is of fundamental importance.

If the union between scion and stock takes place readily, and the growth and development of the combination proceeds without difficulty, it is said to be a congenial union. The degree of congeniality is evidently correlated in some measure with the degree of genetic relationship between the two types united. Apparently, all the different species of *Citrus* commonly grown can be worked on one another successfully, so far as obtaining a fusion of the tissues and a growing plant is concerned; some combinations are much more

successful than others, however, and a wide range in degree of congeniality is thus shown. The commonly grown *Citrus* species (orange, lemon, grapefruit, etc.) can also be worked on various species of genera closely related to *Citrus,* but usually these combinations can scarcely be considered fully congenial, even though commercially successful orchards may be grown with certain of them. As an illustration, oranges propagated on the trifoliate orange, which belongs to a different genus (*Poncirus*), may in some places produce very successful orchards, though the type of union and growth indicates clearly that the combination is not a fully congenial one.

Dr. W. T. Swingle and his associates in the U. S. Department of Agriculture have shown that varieties of the orange can be worked successfully on seedlings of species belonging to such widely distinct genera as *Eremocitrus* Swingle, *Microcitrus* Swingle, *Swinglea* Merrill, *Severinia* Tenore, and the like, but it has not yet been shown that any of these can be considered sufficiently congenial to produce successful commercial orchards. (Consult Vol. I, chap. iv.) It is probable that if the heritage brought to the industry by these citrus relatives is to be of commercial value, it will come through the use of hybrids of these with the orange or some other species of *Citrus.* The possibility will be more fully discussed in a later section. The genera here mentioned are all rather closely related to the genus *Citrus,* belonging to the tribe Citreae. Those species of the Rutaceae which belong to the dry capsular section of the family are so distinct from all *Citrus* species that apparently they cannot be expected to unite in propagation. However, in one experiment conducted in Florida the writer succeeded several times in getting sweet orange buds, inserted on limbs of *Zanthoxylum floridanum* Nutt.,[1] to unite and remain green for about six months, one of them pushing out a weak shoot about ½ inch long before it died. It is clear that the limit of possible fusion was reached and that the degree of relationship was so slight that fusion and life were possible for no more than a short period.

Thus, the possibility of successfully working one plant on another is apparently based on the closeness of genetic similarity or relationship, the degree of congeniality following very closely the nearness of genetic constitution. In general, plants that can be successfully hybridized can be successfully worked together in propagation.

## PHYSIOLOGICAL AND ANATOMICAL RELATIONS OF ROOTSTOCK AND SCION

The influence of the stock on the scion may, in general, be considered similar to an environmental reaction, and the same may also be said of the influence of the scion on the stock. Each of the two distinct portions of the tree retains its individual or genetic characteristics, but these may be modified in expression by the changed conditions, much as they may be modified by a change of environment. The variations are usually quantitative, such as changes in size, longevity, density of color, and the like. The variations caused by the inter-

[1] In *Index Kewensis, Z. floridanum* Nutt. is given as a synonym of *Z. caribaeum* Lam.

actions between stock and scion are here designated "stionic variations."[1] Some of them may readily be explained as results of well-known growth reactions, but for others the fundamental reasons are not known.

In the union of the tissues of stock and scion there is a complete fusion, although the cells of each type retain their individuality. The fusion is thus not accompanied by nuclear fusion, as when sexual gametes fuse, but is merely a fusion by the growing and cementing together of the cell walls placed in close contact with one another. This fusion, however, is limited to the new tissues developed from the growing cells of the cambium layers of stock and scion (see chap. i, p. 27). The old differentiated tissues never unite, but are merely overgrown by the new tissues. That there is rarely if ever a fusion of nuclei in the cells at the point of union is shown by the fact that the sprouts forming in this region where the two tissues are more or less commingled are either of one kind or the other. The writer has examined many thousands of such sprouts originating so near the union that it could not be told whether they were actually from the scion or from the stock, and yet such sprouts invariably were either wholly like the stock or wholly like the scion, showing clearly that they originated from the tissue of one or the other. In citrus, the writer has never seen originating on the line of union a sprout that exhibited the commingling of the two tissues in a chimera. It is entirely possible, however, that such chimeras may occasionally be formed. (See Vol. I, p. 870.)

A stion thus represents an artificially produced symbiosis in which the symbionts live together in a close association that is mutually beneficial, each retaining its own characteristics and heritage.

As the plants that are grafted together grow, the connections of the bark, woody cylinder, vascular bundles, and like tissues of stock and scion are established in such a way that the normal passage of the transpiration stream and certain nutritive materials takes place.

Strasburger (1901) found protoplasmic connections or plasma bridges between the cells of the stock and those of the scion in certain plants; it is thus possible that there is a migration of idioplasm and plasma particles. However, little is definitely known concerning limitations in the passage of different materials. That water, sugars, and the ordinary nutritive materials in solution in the sap pass readily through the tissue unions is evident from the continued growth. It does not seem likely that plastids or organized protoplasmic bodies would pass from scion to stock, or vice versa, but substances such as hormones and enzymes may be expected to do so and to produce characteristic reactions.

Although no instance of stionic reaction in citrus, known to the writer, has been shown to be due to the passage of hormones from one symbiont to the other, certain instances are suggestive of such an influence. Dr. W. T. Swingle,

[1] For the sake of clarity and brevity, several words coined by the writer (Webber, 1932*e*, p. 4) are used in this discussion: *Stion*—any plant or tree composed of a stock and a scion growing in combination. This term is used irrespective of the method employed in propagation, i.e., budding, grafting, inarching, etc. It is formed by combining the first two letters of the word *stock* with the last three letters of the word *scion*. *Stionic*—pertaining to a stion. *Stionic variation*—a variation caused by the reaction between stock and scion.

of the U. S. Department of Agriculture, has informed the writer that in Italy, where the lemon is extensively propagated on sour orange stocks, it was common practice a few years ago to grow also a few small branches of sour orange from buds inserted on the lemon scion trunks. This was said to protect the lemon against infection by foot-rot gummosis at the bud unions and to insure healthy growth of the sour orange stocks. The method has not been practiced in the United States, but in neither country has the sour stock been entirely satisfactory when worked with the lemon.

Dr. Swingle also relates that, in working the wampee (*Clausena Lansium*) with certain *Citrus* species, he found that the grapefruit cannot be successfully budded directly onto the wampee, but can be grown on wampee stocks by using an interstock of Rough lemon, which can be budded onto wampee. It is necessary, however, to allow a few small sprouts, with foliage, to develop from the wampee stock, or the grapefruit top soon begins to lose its leaves and finally dies. The grapefruit top will also decline and die if the wampee sprouts are allowed to grow too large.

The foregoing examples indicate that a substance similar to a hormone and peculiar to the species may be produced in the top growth of the stock tree, and that it must be supplied to the roots, though in limited quantities, to insure the health and continued good growth of the combination.

In the writer's experiments at Riverside, California, five two-year-old budlings each of Eureka lemon, Marsh grapefruit, Valencia orange, and Satsuma mandarin on seedlings of *Severinia buxifolia,* and a similar number of budlings each of Eureka lemon, Marsh grapefruit, and Satsuma mandarin on *Eremocitrus glauca,* were planted in an experimental orchard in 1931 and have been under observation since. The trees of all these combinations were severely dwarfed, and some were weak and sickly; all exhibited a tendency to throw out numerous sprouts from the stock below the bud. After the dwarfing had been observed for two years in the orchard, several sprouts from the stock were permitted to develop on each tree. During the next six years the root sprouts were permitted to grow, but no effect or beneficial influence could be observed.

Went (1938), in investigations of the effect of stock on scion, using different varieties of the garden pea, found that the growth of the scion was not merely a simple nutritional effect, but that the expression of many characters in the scion apparently depended on the presence of growth factors in the rootstock that he considered to be hormones and called "calines." It is quite possible that such hormones may be present in citrus and may influence stionic reactions, but no adequate investigations have as yet been made.

When stock and scion grow well together, it is evident that each symbiont is able to utilize the materials produced or stored in the other. According to Daniel (1894), the reserve materials of the stock are rarely utilized by the graft of a plant of another family. With plants of the same family, the graft, in general, uses the reserves of the stock as though they were its own. A notable exception to which Daniel directed attention was found in the absorption of inulin by stion combinations of the Cichoraceae: only scions with roots

containing inulin absorbed this substance from their stocks. No instance comparable to this is known in the citrus group, but the illustration emphasizes the necessity of retaining a normal physiological balance between the stock and the scion if the union is to be a successful one. However, so little is known about the physiological processes and reactions that take place between stock and scion that there is scarcely any evidence available to indicate what constitutes a normal physiological balance. Such evidence as is available is based almost solely on nearness of genetic relationship and the observation of results obtained by actual trials. Many instances of different physiological reactions will be discussed under other headings.


Fig. 38. Rootstock reactions in citrus, arranged in "minus" and "plus" series according to stock size. The reaction between stock and scion is shown for various rootstocks, as follows: *C*, sweet orange, showing normal good congeniality of stock and scion; *C−1*, good sour orange; *C−2*, medium-good sour orange; *C−3*, bad sour orange; *C+1*, grapefruit; *C+2*, trifoliate orange; *C+3*, China lemon.

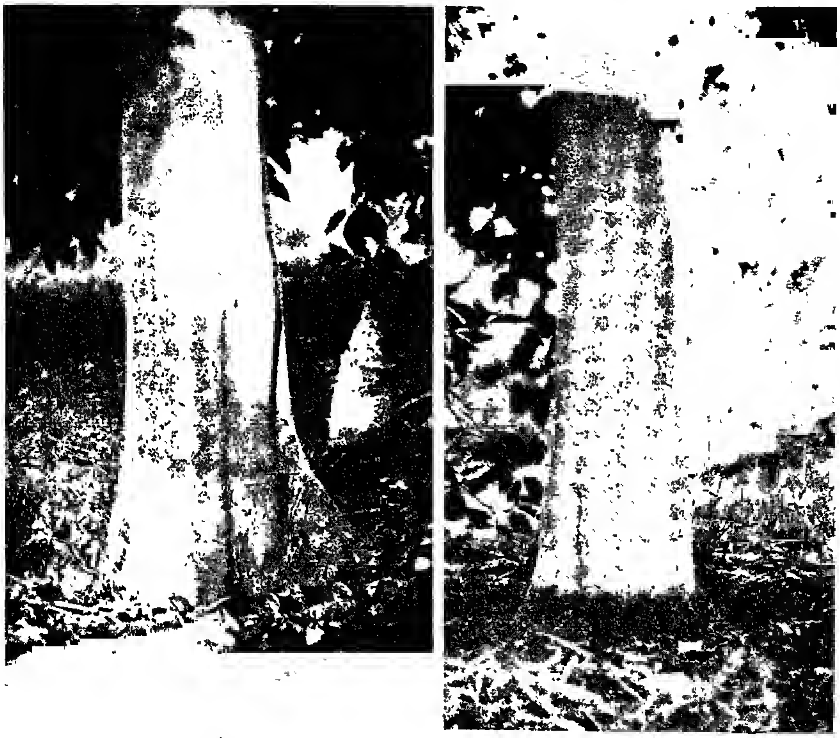
## INTERRELATIONS BETWEEN STOCK AND SCION

### GROWTH REACTIONS AT BUD UNION

The most noteworthy reactions between stock and scion in citrus are intimately related to growth rate and usually can be plainly seen by an examination of the trunks at the point of union. Sometimes the scion overgrows the stock; sometimes the reverse occurs. These reactions pretty clearly represent the degree of congeniality or affinity between the two and provide a means of at least partially predicting the results that are likely to be obtained from a given stionic combination (Webber, 1926, 1927).

The scion and stock reactions commonly exhibited in citrus propagation are illustrated in figure 38. Here the central figure (*C*) shows a type which is interpreted as illustrating thorough congeniality, the bud union being smooth and even and the trunk gradually tapering or decreasing in size from the roots upward, as occurs normally in an unbudded tree. Such a development indicates a uniform balance of physiological functions and growth rate between stock and scion, and a harmony of genetic relationship that permits a thorough and normal fusion of tissues at the bud union. This result is commonly obtained when varieties of the sweet orange, such as the Washington Navel and the Valencia, are budded on good, thrifty sweet orange seedlings, both scions and stocks being the same species (fig. 39). Thorough congeniality

is apparently obtained also when Eureka lemon or Lisbon lemon is budded on certain good types of the sweet orange, or on the Rough lemon. All the data available from extensive observations indicate that stocks and scions giving such uniform growth at the bud union commonly produce long-lived, vigorous, healthy, productive trees.



*A* *B*

Fig. 39. Stionic reactions at bud union indicating thorough congeniality: *A*, Washington Navel on sweet stock (thirty-five years old); *B*, Valencia on sweet stock (fifteen years old).

On each side of the central illustration (*C*), in figure 38, are shown series of reactions that are known to occur with considerable regularity. On the left is arranged a series designated "minus" reactions (*C–1, C–2, C–3*), where the growth of the rootstock is slower than that of the scion. This condition is accompanied, in extreme cases (*C–3*), by a very marked swelling and overgrowth of the scion at the point of union. All these types are exhibited in greater or less degree when navel or Valencia oranges, or especially Eureka lemons, are budded on sour orange stocks (fig. 40). Sour orange seedlings, as commonly used, vary greatly in type and genetic constitution, and this is doubtless the reason for the variation in the reactions obtained.

Figure 38, *C–1,* illustrates a type of reaction obtained where a fair degree of congeniality exists. The bud union is smooth and indicates good fusion and ready passage of nutritive solutions, but the stock trunk develops more slowly and is somewhat smaller than the scion trunk. This is the common result when sweet orange varieties are budded on the sour orange (fig. 41), and is obtained

*A* *B* *C*

Fig. 40. Stionic reactions showing overgrowth of the stock by the scion, with varying degrees of congeniality: *A,* Eureka lemon scion on sour orange stock, badly overgrown and dwarfed (twelve years old); *B,* Lisbon lemon on sour orange stock—a fairly good union for this combination (fifteen years old); *C,* Eureka lemon on sour orange stock, illustrating most common reaction with this combination (thirty-five years old). Note shell-bark disease on lemon trunk (*C*) above union.

in some degree when lemon varieties are budded on the best sour orange stocks. The reaction illustrates a fairly favorable condition, as the bud union is not excessively swollen and the scion is, in general, nearly up to standard in size, or is only slightly dwarfed.

In figure 38, *C–2* and *C–3* represent types of reactions obtained very commonly when varieties of sweet orange or lemon are budded on sour orange stocks. The general reaction is the same as that illustrated in *C–1,* only more pronounced in *C*–2, and extremely marked in *C–3.* In types such as *C–2,* in which the scion is much swollen at the bud union, the scion top is likely to be somewhat dwarfed; and in such extreme types as *C–3* the trees are finally much dwarfed, short-lived, and unsatisfactory. This is noticeably true of Eureka lemon, many groves deteriorating at fifteen to twenty years of age and becoming very unsatisfactory.

Jensen, Wilcox, and Foot (1927) studied the effect of the degree of over-

growth of the scion by correlating the ratio of scion overgrowth[1] to volume of tree top. Different lots (populations) of Eureka lemons on sour orange stocks gave the significant negative correlations of $-0.28 \pm 0.02$ to $-0.61 \pm 0.04$, thus showing clearly that, in general, the larger the swelling at the bud union, the smaller the top. Populations of Lisbon lemon on sour orange also gave negative correlations, but much smaller ($-0.17 \pm 0.03$ and $-0.07 \pm 0.08$) and scarcely significant. Both the Eureka and the Lisbon lemon on grapefruit stocks, on the contrary, gave smaller positive correlations, $+0.09 \pm 0.07$ and $+0.45 \pm 0.08$ respectively, the latter being, apparently, significant.

Fig. 41. Valencia orange on sour orange stock, illustrating typical good union for this combination, many unions being much more swollen. Tree seventeen years old.

Lisbon lemon is less subject to unfavorable reaction on sour orange stock than Eureka lemon, sweet orange varieties are less affected than Lisbon lemon, and grapefruit varieties are apparently normal; but combinations of stocks and scions showing such evidence of uncongeniality are not likely to be long-lived or fully up to standard in size and productivity.

The degree of difference in the overgrowth of the scion is apparently to be explained as due to the different degrees of affinity exhibited by the variable seedlings used as stocks. It is well known that unselected sour orange seedlings are very variable in character, especially in growth rate (Webber, 1920*a*, 1920*b*, 1920*c*, 1932*a*), and similar variability is to be expected in the seedlings of all species or types of citrus that are not largely reproduced by nucellar embryony.

The physiological reason for the development of the swellings above the bud union is not yet fully explained. Similar developments in other combinations of stock and scion have been attributed to some interruption in the passage of nutrient elements, especially carbohydrates, through the fusion tissues at the point of union, a condition leading to their accumulation above the bud and a resultant swelling. Jensen and his co-workers (1927), in a limited study, found a greater accumulation of starch above the bud union

[1] This ratio is obtained by dividing the circumference of the scion just above the union by the circumference of the stock approximately three inches below the union.

with sour stock than with grapefruit stock, but did not extend the study sufficiently to justify the conclusion that this is generally true. This result, however, is in accord with expectations, as the grapefruit stock trunk normally shows a slightly more rapid development than the scion trunk, with both orange and lemon varieties, indicating quite clearly that the carbohydrates produced in the top and required for growth must reach the stock trunk in abundant quantity.

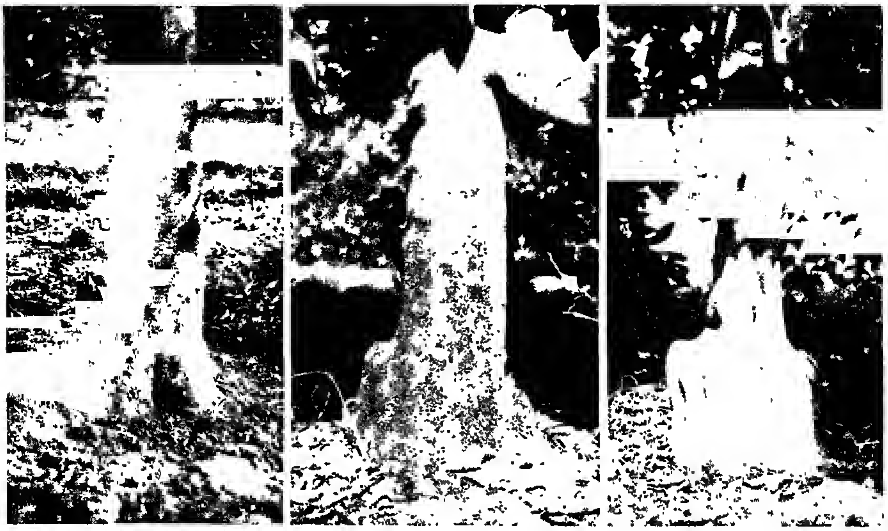
The reactions to girdling, or to cutting of the bark at right angles to the stem, are also of interest in the interpretation of the phenomenon of scion overgrowth. Girdling in citrus and deciduous fruits is known to induce the accumulation of carbohydrates in the tissues above the cut. Such mutilations sever the sieve tubes and interrupt the normal translocation of nutrient materials. This accumulation of carbohydrates in the top portions of the tree, following girdling, is indicated by the increase of soluble solids and reducing sugars in the juice of Washington Navel oranges, as found by Church (1933), and is probably to be considered a common phenomenon following any interruption of the downward transportation of photosynthetic materials. Heinicke (1933, p. 229) found that, with apple shoots, ringing tends to reduce the photosynthetic activity of the leaves and to increase respiration. This is indicated as probably "due to the harmful influence of an accumulation of the products of photosynthesis; possibly also due to the lack of water and nutrients from the soil."

Reichert and Perlberger (1934, p. 201), in their study of the disease xyloporosis on sweet lime stocks budded to Shamouti sweet orange, found that the sieve tubes at and below the bud union were injured and their function apparently impaired. This resulted in an accumulation of photosynthetic products in the scion and an abnormal swelling and overgrowth just above the union (see discussion on pp. 97–98). The fruit on diseased trees also was found to contain increased percentages of total solids and reducing sugars, as was noted in the girdled trees cited above.

It is not possible, with the limited knowledge available, to conclude that the faulty union of uncongenial tissues is the true cause of the overgrowth of the scion as illustrated in figure 38, *C–2*, and *C–3;* but from the similar reactions caused by traumatic influences, such as by girdling or by diseases at the union, it does seem that lack of congeniality may be considered the important factor, even though the physiological reactions are not completely elucidated.

The poor condition of the tops and the sickly appearance of the leaves in severely overgrown stocks might naturally be expected to follow from the injurious influence of too high concentrations of the products of photosynthesis, owing to the interruption of their normal translocation and use. It is, of course, equally true that water supply and nutrients taken from the soil may be interrupted in passage at the union and may contribute to the effect. It is also certain that the failure of photosynthetic products to pass freely to the rootstock would decrease the growth and normal development; a vicious circle is thus formed by the poor union.

The series of reactions illustrated on the right of figure 38, *C*, and designated as the "plus" series, shows the tendencies opposite to those discussed above. Here the growth of the stock is for some reason more rapid than that of the scion, and as a result the trunk of the stock is larger than the scion trunk. Trees of Eureka lemon, navel orange, or Valencia orange budded on grapefruit stocks almost invariably show this larger size of the stock trunk, as illustrated in figure 38, *C + 1* (see also fig. 42, *A* and *B*), but the degree of difference in size is not so marked as in some other cases. In these combinations



A B C

Fig. 42. Stionic reactions showing overgrowth of the scion by the stock, with varying degrees of congeniality: *A*, Valencia orange scion on grapefruit stock (nineteen years old); *B*, Washington Navel on grapefruit stock (twenty years old); and *C*, Washington Navel on trifoliate orange stock (twenty-five years old).

the natural growth rate of the scion and stock types is normally about the same, and thus the increase in the size of the stock trunk apparently cannot be attributed entirely to differences in normal growth rate. The reaction of the scion on the stock in some way stimulates it to a somewhat more rapid growth than normal.

When lemon or sweet orange varieties are budded on the trifoliate orange, which normally is a tree of slower growth and smaller size, the reaction at the bud union is similar to that produced with grapefruit stock, but is more pronounced. The stock is forced into abnormally rapid growth, and the scion is slowed down in growth and commonly dwarfed in size, as illustrated in figure 38, *C+2* (see also fig. 42, *C*). Here, invariably, the stock overgrows the scion. This stock has sometimes been put to practical use in the propagation of navels and other orange varieties to obtain dwarfed trees and early fruiting, but has rarely given satisfactory results over a long period of time, and

orchards of this combination are rarely retained longer than twenty or twenty-five years. There are exceptions, however, which will be discussed later. Lemon varieties on trifoliate orange are even more severely dwarfed and rarely have proved satisfactory.

The overgrowing of the stock trunk in the trifoliate orange budded to sweet orange, grapefruit, or lemon varieties is remarkable. The trifoliate orange is a deciduous tree having a very definite winter rest period, and, in comparison with the evergreen orange and lemon varieties used as scions, has much smaller leaves and very sparse foliage. The common orange and lemon varieties have no very definite winter rest period, but are active more or less continuously. It would seem, therefore, that the reaction here is to be explained by the additional nutrition supplied to the trifoliate orange rootstock, which causes it to grow much more rapidly than it would under normal conditions.

At one time, when taking wood samples with an increment borer from an eight-year-old tree of Washington Navel orange on trifoliate orange stock, at Meloland, California, the writer noted that the resistance to penetration offered by the wood of the much-swollen stock was very slight. Tests on the wood of a normally grown trifoliate seedling of about the same age revealed a much greater resistance to penetration. This difference was interpreted to indicate that the wood of the trifoliate rootstock had been stimulated into rapid sucker-like growth by the greater photosynthetic capacity of the evergreen scion with larger leaf area. A microscopic examination of comparative wood sections showed the various tissue cells of the wood in the overgrown trifoliate stock trunk to be much larger than those in the normal trifoliate orange seedling. Although these were hastily made, isolated observations, they probably represent about what normally occurs.

Orange varieties, especially Valencia, have frequently given excellent results for a limited time on trifoliate stock, but lemons have never succeeded on this stock, and orange varieties frequently fail on it. It is clearly an erratic stock.

Grapefruit stock, on the other hand, which usually slightly overgrows scions of lemon or orange varieties, has frequently given good results. Nevertheless, there have been many indifferent results and failures with the use of grapefruit as a stock with orange varieties.

A greatly enlarged growth of the stock trunk is also produced where the China lemon (*Citrus Medica* Linn.) is used as a stock for varieties of the sweet orange and at least some lemons. Here the overgrowth is apparently fully as severe as with the trifoliate orange, and there is a great tendency to develop sprouts or suckers from the stock (fig. 38, *C+3*), which does not occur with the trifoliate stock. The effect of this overgrowth of the China lemon stock has, in almost every instance studied, proved finally to be injurious.

With any particular combination of stock and variety, considerable variation in reaction can be found, though the general tendency of the seedlings of each stock discussed is to show the reaction indicated. It may be concluded that the uniformity of trunk growth illustrated in figure 38, *C*, generally indi-

cates perfect congeniality between stock and scion, and that any departure from this either way, as illustrated in the series of plus (+) and minus (–) reactions, may be regarded as indicating lack of congeniality and therefore the probability of erratic and undesirable results.

It should be noted that in some unions stock overgrowth does not seem detrimental. Satsuma on trifoliate orange produces marked stock overgrowth; yet this combination is generally satisfactory and the trees are long-lived. In orchards fifteen to thirty years old, trees of Satsuma on trifoliate stocks are commonly much smaller than those of similar age on sweet orange stocks, but old trees, especially in Japan, are known to attain a very large size. It is

TABLE 2

EFFECT OF ROOTSTOCK ON SIZE AND YIELD OF THE MALTA SWEET ORANGE*

| Rootstock | Height of tree | Breadth of top, four feet from ground | Yield, in number of fruits |
|---|---|---|---|
| Rough lemon | 11 ft. 10 in. | 9 ft. 6 in. | 200 |
| Sweet lime | 5 ft. 9 in. | 5 ft. 4 in. | 26 |
| Sour orange | 5 ft. 9 in. | 5 ft. 0 in. | 10 |
| Citron | 3 ft. 6 in. | 3 ft. 0 in. | 16 |

* Tabulated from W. Robertson Brown (1920, pls. II and III).

possible that overgrowth is not itself injurious, but merely indicates lack of physiological balance between the united types, and that other factors not yet determined cause the failure of certain combinations.

## EFFECT OF STOCK ON GROWTH OF SCION TOP

*The same scion variety on different rootstocks.*—The remarkable degree of change in size of stock or scion produced in some combinations in citrus is rarely appreciated. W. Robertson Brown's (1920) experiments on citrus stocks, conducted at Peshawar in India, supply interesting illustrations of such striking changes.

In these experiments, the Malta, a variety of the common sweet orange (*Citrus sinensis*), and the Santara,[1] a variety of the mandarin orange (*C. reticulata*), were budded on four widely distinct stocks: (1) the common sour orange (*C. Aurantium*), (2) the galgal citron (*C. Medica*), (3) the Rough lemon (*C. Limon*), and (4) the sweet lime or sharbete (*C. aurantifolia*). The comparative size and character of root systems and trunks of the various combinations are well shown in figure 43.

The Malta made fine vigorous growth on the Rough lemon, medium growth on the sweet lime, and still less growth on the sour orange and the citron. At four and one-half years from date of planting, an average tree of the Malta on each of the four stocks gave data on size and yield as shown in table 2. The

[1] In the citrus literature of India the mandarin orange is referred to as the Santara, Sangtura, Sùntara, Sùngtara, Santra, etc. In this publication the spelling *Santara*, employed by the Imperial Bureau of Fruit Production (1932), is used except in direct quotations.


**Fig. 43.** Comparative size and character of root systems and trunks in various combinations of citrus rootstocks and scions. The rootstocks, from left to right (*both upper and lower series*), are as follows: (1) sour orange, (2) citron or galgal, (3) Rough lemon, and (4) sweet lime. The scion varieties are Santara mandarin (*upper series*) and Malta sweet orange (*lower series*). (After W. Robertson Brown, 1920.)

Santara (mandarin) made the best growth on the sweet lime and a fairly satisfactory growth on the sour orange, but was markedly dwarfed and unsatisfactory on the Rough lemon and the citron.

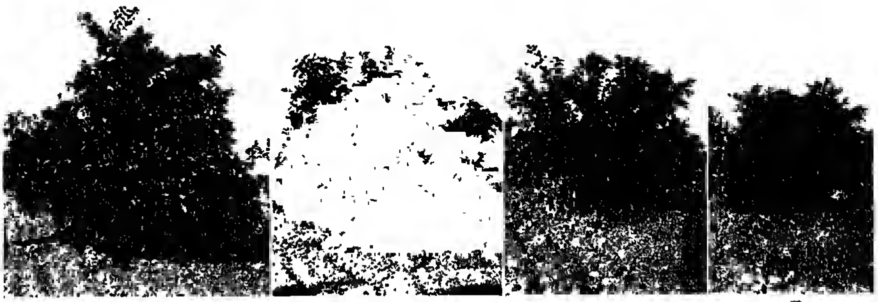
The tendency of the Rough lemon and the sweet lime to produce very abundant lateral roots near the surface, and of the sour orange to produce a well-developed taproot, is shown with the scions of both Malta and Santara, though the trees and roots are of markedly different size (fig. 43). It will be noticed that size of root system is always in the same relative proportion to

Fig. 44. Influence of rootstock on size of scion: Eureka lemon on grapefruit stock (*left*) and on trifoliate orange stock (*right*). Trees eight years old.

size of trunk and top. The citrus industry in Peshawar, India, according to Brown (1920), has been largely a failure because these stionic reactions were not recognized and stocks unsuited to the varieties were commonly used. It should be noted that these reactions do not entirely accord with experience in the United States, where mandarin varieties usually grow vigorously on Rough lemon stocks, the growth equaling or exceeding that on sour orange.

Bonns and Mertz (1916) have presented evidence concerning the comparative size of trees of Washington Navel, Valencia orange, and Eureka lemon at seven years of age, when grown on sweet orange, sour orange, grapefruit, and trifoliate orange stocks at the California Citrus Experiment Station. The sweet orange stock produced the largest trees in every plot except one; in this plot of Washington Navels grown on shallow soil, trees on sour orange stock were slightly larger than those on sweet orange stock. With the scion varieties tested, trees on grapefruit and sour stocks were next in size to trees on sweet orange, those on grapefruit stock averaging somewhat larger than those on sour stock.

The trifoliate orange, which shows the least affinity with the scion varieties tested, reacted differently with the different varieties. The most adverse condition was shown with the Eureka lemon, the average size of top in all plots being only about one-sixth of that of Eureka on sweet orange and only slightly more than one-fifth the size of Eureka on sour orange or grapefruit (fig. 44). In general, Washington Navels and Valencias on trifoliate stock were about one-fourth smaller than the same varieties on sweet; but it is noteworthy that on the deep and rather heavy soil of one plot the Valencias on trifoliate orange



*A* *B* *C* *D*

Fig. 45. Influence of rootstock on size of scion: Marsh grapefruit on (*A*) Homosassa sweet orange, (*B*) Brazilian sour orange, (*C*) Cunningham citrange, and (*D*) trifoliate orange. Trees four years old. Brawley, California.

were comparatively of the same size as those on sweet orange and larger than those on sour orange and grapefruit. The trees on trifoliate stock in this plot, at twenty-five years of age, continued to retain their same relative position and were considered to be standard-sized trees.

Dwarfing effects of the trifoliate orange similar to those described above were also obtained by G. L. Taber in carefully planned experiments conducted in Florida (Hume, 1913, p. 208).

The range of variation in size exhibited by the Marsh grapefruit on different rootstocks is illustrated in figure 45. These are photographs of average-sized trees grown at Brawley, California, on a heavy loam soil in the rootstock experiments of the California Citrus Experiment Station. The trees were only four years old when photographed, but the same relative size has been maintained through a period of twelve years. Trees of the same combinations in the experiments at Riverside exhibit the same comparative sizes. In the same experiments, the trees of Marsh grapefruit on Rough lemon and grapefruit stocks were of approximately the same size as those on sweet orange stock, and were larger than those on sour orange stocks. (Compare table 14, p. 200.)

Frequently, in field plantings, marked differences in size have been observed in old trees of the same variety on different stocks, when growing side by side under approximately uniform conditions. A divergence of this kind, in twenty-five-year-old trees of Valencia on sour orange and on sweet orange stocks, was studied by the writer at Lindsay, California (see fig. 46), where

two sections of a grove on comparatively uniform soil had been planted at the same time, one section with Valencias on sour orange and the other with Valencias on sweet orange. When studied, the trees were apparently in equally good health, but those on sour orange rootstocks were markedly smaller in size. An even more striking difference was observed by the writer in a thirteen-year-old grove of Valencia oranges in Florida. There, on a light sandy soil, the Valencias on Rough lemon stocks were much more vigorous and fruitful

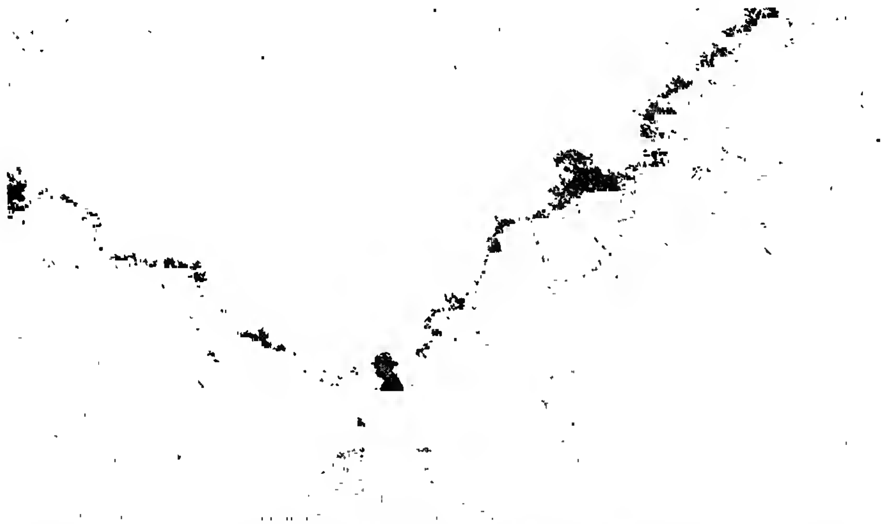


Fig. 46. Influence of rootstock on size of scion: Valencia orange on sour orange stock (*left*) and on sweet orange stock (*right*). Trees about twenty-five years old. Lindsay, California.

than those on sour orange stocks (see fig. 51, p. 105). It seems probable that the difference in growth on these two stocks was primarily caused by the variation in adaptability of the two stocks to the soil. In the rootstock plots of the California Citrus Experiment Station at Tustin, on a fairly heavy loam soil, the seventeen-year-old Valencia trees on sour orange stocks were fully as large as those on Rough lemon stocks (see table 11, p. 176).

Although stocks that have a severe dwarfing effect have not been generally employed in commercial citrus culture, the utilization of such dwarfing combinations as pear on quince stock, apples on Paradise stock, and cherries on Mahaleb stock have nevertheless a definite place in the culture of deciduous fruits. It is not improbable that a dwarfing stock found to react satisfactorily and to give small but productive, long-lived trees, may ultimately prove of service in the citrus industry. The use in China of such slow-growing, semi-dwarfing stocks as the Ponki (Cleopatra) and Sunki mandarins in the propagation of the fine mandarin varieties Ponkan and Tankan may be the factor that permits the very close planting, high yields, and high returns realized there with these varieties (T. Tanaka, 1929*a*). The important factor in prac-

tice is to know the type of reaction each stock produces, as a guide to the arrangement of the orchard, distance of planting, and so on.

*Different scion varieties on the same rootstock.*—Reactions of different scion varieties on the same rootstock may also differ markedly, as has been indicated by the data presented in the preceding section. In the experiments of W. Robertson Brown (1920), the two scion varieties Santara mandarin orange and Malta sweet orange, each on four different stocks (sour orange,

Fig. 47. Reactions of different scion varieties to the same rootstock: Valencia orange (*left*) and Homosassa orange (*right*), both on sour orange stock. Trees thirteen years old. W. W. Youthers grove near Orlando, Florida.

galgal citron, Rough lemon, and sweet lime or sharbete), exhibited marked differences in size of trunk and root system on the same rootstock (see fig. 43).

A variation in size of the two sweet orange varieties Valencia and Homosassa, both on sour orange stocks, is shown in figure 47. These two varieties are commonly supposed to produce trees of about equal size and vigor, but here on a medium fine sandy soil they have responded differently on the same stock.

In trials with about twenty-five rootstock varieties planted in the years 1927–1931 at the California Citrus Experiment Station a different growth rate is evident with almost every scion variety on every stock variety, the size of each scion variety on the various stocks ranging from dwarfed to large standard. It is noteworthy that the trees in the different repeat plots of the same combination, if on approximately the same type of soil, are of about the same comparative size. It is also to be noted that the trees in each plot, where the rootstocks were chosen by proper nursery methods, all exhibited close uniformity in size. Apparently, each rootstock variety tends to

produce the same general growth reaction in the various scion varieties when grown on the same soil and under the same climatic conditions. If the stock that gives the most vigorous growth produces finally a large-sized tree, it can readily be conceived that in a long series of years a somewhat slower-growing stock, if equally long-lived and productive, might, because of closer planting, give equally good yields per acre and be more satisfactory because of the greater ease in handling.

### EFFECT OF SCION ON ROOT SYSTEM

Although the root system is doubtless greatly influenced by the kind of scion grown on it, few definite statements can be made regarding the influence

TABLE 3

ROOT WEIGHT AS PERCENTAGE OF TOTAL PLANT WEIGHT FOR DIFFERENT VARIETIES OF CITRUS ON TRIFOLIATE STOCK*

| Scion variety | Root weight (per cent of total) | Scion variety | Root weight (per cent of total) |
|---|---|---|---|
| Valencia orange | 47.1 ± 2.18 | Kinokuni mandarin | 45.5 ± 3.34 |
| Joppa orange | 55.5 ± 2.94 | Satsuma mandarin | 38.0 ± 0.87 |
| Washington Navel orange | 49.3 ± 1.23 | Mato shaddock | 37.6 ± 1.17 |
| Thomson Navel orange | 43.9 ± 2.52 | Villafranca lemon | 31.0 ± 0.76 |

* Rearranged from Y. Tanaka (1931).

itself. Very little special study has been given to the reactions shown by roots. If the congeniality between scion and stock is good, so that a vigorous scion growth is produced, it is certain that a large and abundant root growth has taken place. On the other hand, if the relation between scion and stock is poor and the scion top is moderately or severely dwarfed, it is certain that the root system of the stock will exhibit similar dwarfing in a comparatively equal degree. This is in conformity with the well-known complementary physiological functions between root and top and is the common observation of growers and experimenters the world over. It was demonstrated by the work of W. Robertson Brown (1920) and is clearly shown by his illustrations (fig. 43, p. 81).

Size relations between scion and stock will differ markedly with different combinations, but few such comparisons have been made. The Japanese investigator Y. Tanaka (1931) has given data for several different citrus varieties, all grown on trifoliate orange stock; and his ratios of weight of roots to total weight of plant for the commonly known varieties are presented in table 3.

These percentages are based on the average weight of six to eight plants of each combination, and indicate differences that are apparently significant. It is evident that such percentages indicate only the relative balance of weight between root growth and scion growth, not the comparative growth of different combinations. Tanaka concluded that "when the congeniality between stock and scion is perfect, the habit of the top strongly reflects upon the mode

of growth of root." He also stated that the roots of the trifoliate orange when budded to lemon exhibited a lighter coloration.

Halma (1934) found that root or stem cuttings of the sour orange develop marked taproots like those of seedlings,[1] but that when such cuttings are grafted with lemon scions and grown they develop only spreading lateral roots similar to those of the lemon. The effect of the sour orange scion grafted on Eureka lemon, however, did not modify the root system of the lemon stock. He also found that bark extracts of roots of the sour orange stock, developed after grafting to lemon scion, gave a color reaction which was neither that of lemon roots nor that of sour orange roots, although much closer to the former than to the latter. Roots of lemon stock grafted to sour orange were

TABLE 4

COMPARATIVE YIELDS AND SIZES OF TREES ON SOUR ORANGE AND TRIFOLIATE ORANGE ROOTSTOCKS

| Rootstock | Average number of fruits per tree | | Average tree size at 39 months | |
|---|---|---|---|---|
| | At 27 months | At 39 months | Height | Breadth |
| Sour orange | 13 | 69 | 8 ft. 2 in. | 9 ft. 2 in. |
| Trifoliate orange | 57 | 93 | 6 ft. 2 in. | 7 ft. 0 in. |

apparently not affected with respect to color reaction of bark extract. In both combinations, however, it was noticeable that the external color of the roots resembled more closely that of the scion variety than that of the stock.

## EFFECT OF ROOTSTOCK ON PRECOCITY OR EARLY FRUITING

Not infrequently the unproductive juvenile period of development is longer when a variety is budded onto a vigorous-growing stock. In general, stocks that have a dwarfing effect tend to stimulate precocity or early fruiting. In experiments conducted by G. L. Taber at Glen St. Mary, Florida (Hume, 1913, pp. 208–212), tests were made of twenty-three standard varieties of oranges and grapefruits on sour orange and trifoliate orange stocks, there being two trees of each combination. Table 4 gives the average total yields of all these trees at 27 months and at 39 months of age, and the average height and breadth of top at 39 months.

Some difference was exhibited by different varieties, but the general effect of the trifoliate orange stock in producing early fruiting is clearly evident. It will be noted that the trees on trifoliate stocks were much reduced in size. Although dwarfed trees are very fruitful, the orchard yields of such trees will not commonly equal those of trees on standard stocks, which soon develop much larger fruiting surfaces and thus give larger orchard yields. The

[1] Dr. W. T. Swingle in conversation has informed the writer that he did not get "marked taproots" in several hundred cuttings each of sour and sweet orange, but only spreading, branched roots.

precocity of such varieties as the Satsuma and Washington Navel orange on trifoliate orange stocks has been observed also in the Riverside experiments, and this is now a well-recognized influence of this stock.

Schultz (1938, 1939) has especially emphasized the precocity, in Argentina, of trees of Ruby, Jaffa, and Valencia sweet orange, and of McCarty grapefruit, when grown on stocks of the Rangpur lime.

It is not likely that the slight degree of precocity caused by any stock is to be considered of much practical importance, as the amount of fruit produced by young trees is not sufficient to influence greatly the financial returns. Long-continued high productivity is a more desirable character.

### EFFECT OF ROOTSTOCK ON SEASON OF FRUIT RIPENING

Apparently, slow-growing stocks with a dwarfing tendency tend to hasten fruit ripening. In the stock experiments at the California Citrus Experiment Station, in some seasons, Washington Navel oranges on trifoliate orange stock have colored in the fall nearly two weeks earlier than the fruits of the same variety on sour and sweet stocks. This effect, however, was partly seasonal and in ordinary seasons is not exhibited to the same degree. In these experiments, also, Eureka lemons on trifoliate stocks colored earlier than those on other stocks, producing a high percentage of tree-ripe fruits of poor quality. Williams (1911) states that in Alabama the Satsuma orange on trifoliate stock ripens its fruits several days earlier than Satsuma on any other stock.

The season of maturing is determined mainly by the scion variety, and one chooses early or late varieties in accordance with what is judged to be the market demand, but an early variety may be rendered slightly earlier by propagating it on a stock that tends to produce early ripening. The effect of the trifoliate stock in this direction is probably connected with its tendency to become dormant very early in the fall, which is a marked general character of deciduous types in comparison with evergreen types.

### EFFECT OF ROOTSTOCK ON SIZE, SHAPE, AND GRADE OF FRUIT

In general, the fruits of any variety retain the principal characters of that variety, irrespective of the stocks on which they are grown; they may, however, be affected by the stock in the quantitative expression of certain characters, in the same way that environment affects these characters. The results obtained in India by W. Robertson Brown (1920) supply some excellent illustrations. On the sweet lime or sharbete stock, the fruits of the Malta orange were distinctly oval in shape, and pale, unattractive, lemon-yellow in color. The seeds averaged about seven in number, and the juice was moderately abundant, sweet, and better in flavor than that of the fruits on any of the other stocks used in the trials, which were the Rough lemon, citron, and sour orange.

On the Rough lemon stocks in the same experiment, the fruits of the Malta were large and rather coarse, perfectly globular, rich attractive orange in color, and inclined to be thick-skinned. The juice was very abundant, sparkling, and, especially on young trees, inclined to be somewhat too acid. The

seeds were numerous and large, usually numbering about sixteen or seventeen. The comparative size, shape, and skin thickness of the Malta oranges on these two stocks are shown in figure 48.

Bonns and Mertz (1916, p. 295), in reporting on the 1907 rootstock experiments at the California Citrus Experiment Station, where sweet, sour, grapefruit, and trifoliate stocks were used, had this to say with reference to

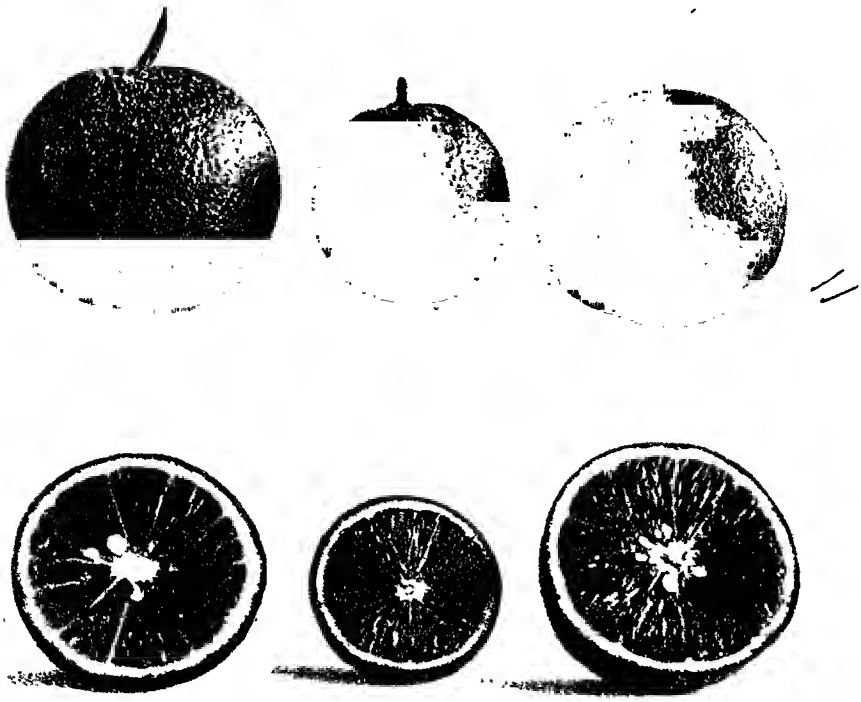


Fig. 48. Stionic variations in fruit of Malta orange grown on different stocks. Fruits at left and at right were grown on Rough lemon stock; fruit at center, on sweet lime stock. (After W. Robertson Brown, 1920.)

the separation of the Washington Navel and Valencia oranges on the different stocks into the standard grades of fancy, choice, standard, and culls:

"The percentage [of fruit] of each grade for any one variety in the same section appears to have no relation to the particular root; seldom are such differences greater than 4 or 5 per cent. The one exception is Valencia on pomelo, [in Plot] B 'shallow' [soil], where 'fancy' fruit of trees on trifoliate falls considerably below the same grade from trees on sweet and pomelo stock. It is not much below the grade per cent of fruit on sour stock.

"Quality differences are more evident in the case of the lemon. Here we may note that although the respective grades run close to each other for sweet, sour, and pomelo stocks, they fall off noticeably in each block when

trifoliate root has been used. There is a lower percentage of fancy and choice, and a relatively higher amount of standard and cull fruit."

Rapid-growing stocks such as the Rough lemon tend to produce fruits that are thick-skinned, rough, and coarse; but it is only under occasional conditions that such characters are developed to a seriously detrimental degree.

## EFFECT OF ROOTSTOCK ON QUALITY OF FRUIT

*Sugar-acid content.*—The idea is frequently expressed that oranges are sour because they are budded on sour orange or lemon stocks; but such effects, if they occur, are not common.

Hume (1926, p. 205) cites fruits from adjoining trees of the same variety, one on Rough lemon stock and the other on sour orange, which showed a difference in acid content that was appreciable to the taste. Chemical analyses of the juice of specimens from the sour stock gave 0.72 per cent acid and 9.8 per cent sugar, determined as dextrose, while those from the Rough lemon stock gave 0.91 per cent acid and 7.24 per cent sugar, determined as dextrose. The fruits on sour stock thus contained 0.19 per cent less acid and 2.56 per cent more sugar than those on Rough lemon stocks.

Quinn (1932), of the South Australia Department of Agriculture, has presented data on the difference in acid, sugar, and juice content of fruits of four varieties on several different stocks grown in the Berri Experimental Orchard. In general, analyses were made every two weeks during the harvesting period of each variety, the samples consisting of twelve oranges from each of the several trees of each variety on each stock. The average percentages of acid (as citric), sugar (as total soluble solids), and juice (by weight) of all samples of each variety on sweet orange and Rough lemon stocks are given in table 5. It will be seen from these data that fruits of each variety on sweet orange stocks contained slightly more acid and more sugar than those on Rough lemon. These increases are not great, but as they are consistently in the same direction they seem to be significant. The same varieties on grapefruit and trifoliate orange stocks gave comparatively the same results as on sweet stock.

It is apparently true that the large, coarse fruits produced under conditions of forced growth, especially on young trees, are commonly low in sugar content, and that such fruits are more commonly produced on rapid-growing stocks such as Rough lemon than on more slowly growing ones. In Quinn's experiments it was found that almost without exception the small fruits on each tree gave a slightly higher percentage of acid and sugar than the larger fruits on the same tree. The different varieties exhibited significant differences in average juice content, the Valencia averaging high, but the influence of the stock on juice content was slight and inconsistent and is probably not to be considered significant (see table 5).

Similar rootstock influences have also been reported by a number of other investigators. Hodgson and Eggers (1938) tested fruits of Washington Navel and Valencia oranges, Eureka and Lisbon lemons, Marsh grapefruit, and Bearss lime, grown on sweet orange, sour orange, trifoliate orange, Rough lemon, and grapefruit stocks. Among them all, trifoliate orange, the most

dwarfing stock, gave the highest content of soluble solids, and the Rough lemon, the most invigorating stock, gave the lowest soluble-solids content. The Rough lemon produced the lowest citric acid content and the trifoliate showed a marked tendency to produce the highest acid content. Similar data apparently taken from studies of fruits from the same trees were reported later by Richards (1940), who also included data on the influence of the same stocks on fruits of the Satsuma and Dancy mandarins and the Rough lemon. Richards' results were practically the same as those reported earlier by Hodgson and Eggers (1938), but he found the marked difference between the

TABLE 5

INFLUENCE OF ROOTSTOCK ON ACID, SUGAR, AND JUICE CONTENT OF CITRUS FRUITS*
(Averages of all tests throughout season)

| Scion variety | Per cent acid (as citric) | | Per cent sugar (as total soluble solids) | | Per cent juice (by weight) | |
|---|---|---|---|---|---|---|
| | Rough lemon stock | Sweet orange stock | Rough lemon stock | Sweet orange stock | Rough lemon stock | Sweet orange stock |
| Washington Navel.... .... | 0.92 | 1.04 | 10.85 | 11.15 | 40 66 | 41.76 |
| Thomson Navel..... .. | 0.79 | 0.94 | 11.14 | 12.24 | 33.23 | 34.80 |
| Mediterranean Sweet. | 0.71 | 0.93 | 11.61 | 12.45 | 38.32 | 38.57 |
| Valencia.. .............. | 0.88 | 1.17 | 10.92 | 12.04 | 48.55 | 47.17 |

* Table adapted from Quinn (1932).

influence of the trifoliate orange and the Rough lemon stocks to be even more pronounced on the two mandarin oranges.

Fudge (1940) and Fudge and Fehmerling (1940) found that the Pineapple orange, in Florida, produced higher concentrations of citric acid, total solids, and total sugars when grown on sour orange stocks than when grown on Rough lemon stocks. Harding (1940) and Harding, Winston, and Fisher (1940), also working in Florida, have reported similar results in investigations made with Parson Brown and Valencia oranges on various rootstocks. They found that degree of acidity, amount of sugar, proportion of acidity to sugars, and aroma—all of which are factors affecting the quality or flavor of orange juice—are affected in large measure by the kind of rootstock on which the fruit is grown. Higher quality resulted when the fruit was grown on sour orange rootstocks than when it was grown on Rough lemon. Probably the most extensive and reliable data showing the influence of rootstocks on the sugar and acid content of citrus fruits are the analyses reported by Sinclair and Bartholomew (1944) on fruits from the rootstock experiments of the California Citrus Experiment Station (see discussion, chap. iii, pp. 185 and 193, and figs. 77 and 82).

*Vitamin content.*—The vitamin content of citrus fruits is of great importance and is apparently influenced in some degree by the rootstock. Harding, Winston, and Fisher (1939, p. 368), as a result of their studies in Florida, stated: "Some rootstock[s] seemed to have an influence on the ascorbic acid

[vitamin C] content of the fruit, especially up to the time of ripening . . . the fruit from the sour orange stocks [as compared with those on Rough lemon stocks] consistently contained the higher amounts of ascorbic acid. . . . The ascorbic acid content of oranges grown on grapefruit, sweet orange, and Cleopatra stocks was about the same as of fruit grown on sour orange stock." As an illustration, the Parson Brown orange on sour orange stock, according to their analyses at different periods in 1936–37 (Harding, Winston, and Fisher, 1940, tables 10 and 11), gave an average of 0.567 mg. of ascorbic acid per milliliter of juice, and those of 1937–38, an average of 0.576 mg. per milliliter. On comparable Rough lemon stocks similar averages for the same two years were only 0.465 and 0.483 mg. per milliliter of juice. This is an increase of 22 per cent in ascorbic acid for the sour orange stock in the first year and of 19.3 per cent in the second year. The authors also stated that no correlation was found between the ascorbic acid content of orange juice and its quality, as judged by taste (see also Harding, 1940).

Fudge and Fehmerling (1940), also working in Florida, have reported that Pineapple oranges grown on sour orange stocks gave higher vitamin-C content than those grown on Rough lemon stocks.

### STIONIC INFLUENCE ON CHEMICAL COMPOSITION OF STOCK AND SCION

In a study of the chemical changes induced as a result of stionic influence, Haas and Halma (1929) found that, at least in some cases, the scion greatly influences the percentage of soluble magnesium in the dry matter or ash of the stock. Analyses of bark from unbudded seedlings of different species of *Citrus* showed percentages of magnesium in the dry matter as follows: Rough lemon (3 trees), 0.036; sour orange (3 trees), 0.026; sweet orange (3 trees), 0.070; and grapefruit (1 tree), 0.086. The Rough lemon and sour orange, it will be observed, are low in magnesium, while the sweet orange and grapefruit are high. When different citrus varieties were worked together, the magnesium content of the bark of the stock varied according to the scion variety with which the stock was united. When the scion was lemon or sour orange, both of which are normally low in magnesium, and the stock was sweet orange or grapefruit, both of which are normally high, the magnesium content of the stock variety was much depressed. On the other hand, if the sweet orange or grapefruit was used as the scion, with lemon or sour orange as the stock, the magnesium content of the bark of the stock variety was considerably higher than normal.

In one of the most interesting experiments described by Haas and Halma (1929), trees which were originally Marsh grapefruit on sweet stock were later top-worked to Eureka lemon. The average values for the grapefruit interstock as well as for the sweet stock were approximately the same as those for the lemon scion, being thus much lower than those normally found in grapefruit and sweet orange. These authors found approximately the same percentage of calcium in the ash of all bark samples analyzed, regardless of the stionic relation.

A very striking illustration of stionic variation in the intake and content of boron is supplied by the studies of Eaton and Blair (1935), who used reciprocally grafted plants of lemon and *Severinia buxifolia,* grown in controlled cultures receiving different amounts of boron. The lemon is known to be highly sensitive to boron. *Severinia,* however, was shown by Swingle, Robinson, and May (1928) to be very tolerant to it, and they suggested the possible feasibility of using *Severinia* as a resistant rootstock for the lemon and orange in regions where boron injury occurs.

TABLE 6

BORON ABSORPTION BY STIONIC COMBINATIONS OF LEMON AND SEVERINIA PLANTS GROWN TWENTY-TWO MONTHS IN SAND-CULTURE SOLUTIONS, DETERMINED AS CONCENTRATIONS OF BORON (PARTS PER MILLION, DRY WEIGHT) IN LEAVES*

| Plant | Boron in culture solution | | |
|---|---|---|---|
| | 2 p.p.m. | 4 p.p.m. | 6 p.p.m. |
| Eureka lemon on own roots | 680 | 1,065 | Dead |
| Eureka lemon on *Severinia* roots | 223 | 283 | 517 |
| Lisbon lemon on *Severinia* roots | 253 | 397 | 457 |
| *Severinia* on Eureka lemon roots | 528 | 877 | ... |
| *Severinia* on own roots | ... | . . | 390 |

* After Eaton and Blair (1935).

Eaton and Blair (1935) found that the boron content is not uniform throughout the plant, but tends to accumulate in the leaves. Rooted lemon cuttings grown in a nutrient solution containing 5 parts per million (p.p.m.) of boron gave leaves containing 1,232 p.p.m. of boron, while the combined stems and roots contained only 54 p.p.m. Hence, in their experiments the leaves were mainly used as the indicators of boron content. Reciprocally grafted plants of lemon and *Severinia* were grown in nutrient solutions containing different concentrations (2, 4, and 6 p.p.m.) of boron. Table 6 gives the average concentrations of boron found in the leaves of these plants after twenty-two months of growth in the nutrient solutions.

Plants of lemon on *Severinia* roots had only about one-third as much boron in their leaves as those of lemon grown on their own roots, and the boron concentration in leaves of *Severinia* was increased threefold in the plants grown on lemon roots. Plants of lemon on their own roots were much more severely injured than those grown on *Severinia* roots. Eaton and Blair conclude (1935, p. 423): "The boron concentrations accumulating in the leaves of the scion were directly influenced by the rootstocks upon which they were grown. The scion leaf concentrations were reduced if grafted to varieties normally accumulating lesser concentrations and increased if grafted to varieties normally accumulating higher concentrations. Concentrations of boron in scion leaves tended to approach those normal to the rootstock variety." Here, the rootstock tended to exercise the controlling influence on the quantity of boron accumulated in the scion, whereas in the studies on magnesium content (Haas and Halma, 1929) it was apparently the scion that exercised it.

## EFFECT OF STOCK AND SCION ON RESISTANCE TO COLD

It is generally believed that a hardy, cold-resistant stock has the tendency to render a tender scion more hardy, and that a tender scion may, on the contrary, render a normally hardy rootstock more tender.

In a study of the effects of the 1913 freeze in California (Milliken *et al.*, 1919, p. 282), a few observations seemed to indicate a stock influence on the scion. In one grove, lemon trees on trifoliate orange were hardier and showed less injury than similar trees on sour orange; in another, navels on trifoliate orange roots appeared to be distinctly less injured than navels on sweet stock planted in the same grove at the same time and given the same treatment.

TABLE 7

FROST INJURY TO FOUR-YEAR-OLD ORCHARD TREES OF OWARI SATSUMA ON VARIOUS ROOTSTOCKS, AND OF WASHINGTON NAVEL ON SOUR ORANGE STOCK, COMPARED*

| Stionic combination | Total number of trees | Percentage of trees injured as classified[a] | | |
|---|---|---|---|---|
| | | Firsts | Seconds | Thirds |
| Owari Satsuma on: | | | | |
| Trifoliate orange | 24 | 58.3 | 29.2 | 12.5 |
| Tangerine | 32 | 21.9 | 37.5 | 40.6 |
| Citrange | 49 | 12.3 | 6.1 | 81.6 |
| Sour orange | 39 | 10.3 | 28.2 | 61.5 |
| Sampson tangelo | 15 | 6.6 | 66.6 | 26.8 |
| Sweet orange | 45 | 6.7 | 11.1 | 82.2 |
| Duncan grapefruit | 4 | 0.0 | 0.0 | 100.0 |
| Rough lemon | 19 | 0.0 | 0.0 | 100.0 |
| Washington Navel on: | | | | |
| Sour orange | 154 | 1.9 | 2.6 | 95.5 |

* After Webber (1935).

[a] *Firsts:* scions alive, so that buds could be saved. *Seconds:* scions killed, but stocks alive. *Thirds:* scions and stocks killed to the ground.

Hume (1926) reports that in a nursery containing trees on Rough lemon, sour orange, and trifoliate orange stocks every tree on Rough lemon was killed to the ground by cold, and trees on sour orange were appreciably damaged, but those on trifoliate orange escaped injury.

A good illustration of the effect of rootstocks on the degree of frost resistance of the scions is supplied by the California experiments on rootstocks in plots at Oroville, California (Webber, 1935). In these plots four-year-old trees of Owari Satsuma on various rootstocks (stocks eight years from the seed) were practically destroyed by the freeze of December, 1932. Several months after the freeze, the trees were thoroughly examined and classified into three grades: (1) those showing the least injury and sprouting well above the bud, so that the buds could be saved; (2) those showing medium injury, with stock and scion trunk partially living and sprouts forming, but so girdled by dead areas that the buds could not be saved; and (3) those most severely injured, both scion and stock being so harshly affected that they were killed to the ground (all trees were budded about six inches high). The results are sum-

marized in table 7. In this table all rootstock varieties of the same species are classed together and listed in the order of degree of tree injury. It is evident from an examination of this table that the rootstock did have a very marked influence on the degree of injury, which ranged from 58.3 per cent "firsts" (trees least injured) on trifoliate orange stock to 100 per cent "thirds" (trees dead) on Rough lemon stock. Note also the comparative injury to four-year-old Washington Navels on sour orange stock (bottom of table 7). These navels were in the same orchard and surrounded the planting of Satsumas on all sides.

The effect of the trifoliate orange stock in producing hardiness is probably to be attributed, in general, to its tendency to remain dormant through the winter period. Williams (1911, p. 155) states: "The fact that this stock is not responsive to sudden changes in temperature, especially to those warm spells which generally start activity in other trees during January and February, adds greatly to its value. There is no question but that the stock has a very marked influence on the top growing upon it."

That other stocks than the trifoliate orange have some influence in rendering the top more cold-resistant is probably true, but the differences are so slight that they would be apparent only in light freezes, for in severe freezes all the trees, usually, are badly injured.

Uphof (1938), in studying the effects of freezes in Florida, found that the rootstock had a great influence on frost resistance of citrus trees. Trees of the orange varieties Parson Brown, Hamlin, Pineapple, and Valencia, and of the grapefruit varieties Duncan, Hall, Walters, and McCarty, on sour orange stocks, were found to be appreciably less injured than similar trees on Rough lemon stocks. Orange varieties on Cleopatra mandarin stock were found to exhibit a considerable degree of frost resistance. An objection to the general use of this stock, it was stated, is that, except with the Temple orange, trees on it tend to bear smaller fruits than on other rootstocks. Rootstocks of trifoliate orange were observed to increase greatly the frost resistance of varieties budded on it, but the use of this stock is limited principally to the Satsuma.

In some nursery budlings there is apparently a definite influence of the scion upon the stocks. In the 1913 freeze in California (Milliken *et al.*, 1919), one-year-old buds of Eureka lemon inserted about four inches above the ground on sour orange and grapefruit seedlings were killed, and the stock trunks were also killed back to three or four inches below the bud, while unbudded sour orange and grapefruit seedlings of the same age, mingled with them, showed only a slight injury to the foliage.

## EFFECT OF STOCK ON WIND INJURY TO TREES

Reed and Bartholomew (1930) described an occurrence in which the influence of a severe wind on fruit drop of navel oranges apparently varied with the stock. The average weight of oranges lost per tree was, for sweet orange stock, $4.85 \pm 0.37$ lb.; for sour orange stock, $6.92 \pm 0.46$ lb.; and for trifoliate orange stock, $20.45 \pm 2.15$ lbs. Here it was interpreted that the difference as between sweet and sour stocks was not significant, but that the loss from trees

on trifoliate stock was so much greater as to indicate that the rootstock had a definite influence on the fruit abscission.

Bœuf and Genêt (1906) noted a reduced resistance to wind injury of trees on the bigarade or sour orange (*Citrus Aurantium*). On the other hand, in the West Indies and other islands of the Caribbean Sea region, where trees in large numbers are sometimes uprooted by hurricanes, the sour orange has proved most resistant to injury. Freeman (1931) states that in Dominica, where the lime has been propagated mainly as seedlings, which are easily uprooted, considerable progress has been made in propagating on sour orange rootstock, which has been found more resistant to hurricane injury.

Schultz (1939) has stated that midseason varieties of oranges on Rangpur lime stocks will hold their fruits better through periods of hot winds and excessive temperatures than the same varieties on sour orange stocks.

### STIONIC INFLUENCE ON SUSCEPTIBILITY TO DISEASE

That different species and varieties of citrus vary greatly in their susceptibility to various diseases is well known. It has generally been considered that the degree of resistance exhibited by either the stock or the scion is not imparted in any recognizable degree to the other member of the combination. The writer has observed in nurseries and orchards in Florida many trees with citrus scab (verrucosis) prevalent on sprouts or suckers of the sour orange stocks but no sign of the disease on the sweet orange foliage of the scion. Scaly bark is frequently observed to run down the sweet orange trunk to the union with the sour stock and stop there abruptly. In like manner shell bark may be very bad on the lemon scion trunk, yet stop abruptly at the union with the sour rootstock. Such observations, frequently made, have led to the conclusion that there is little stionic influence so far as disease resistance or susceptibility is concerned.

Nevertheless, there are records to show that one member of the combination seemingly has been rendered more or less resistant through stionic influence. In Java, Toxopeus (1931) found that when stocks and scions both of which were susceptible to root-rot gummosis were budded together, 45 per cent of the stocks were attacked by the disease within two years. However, when immune scions were budded on susceptible stocks, not a single stock contracted the disease even after six years.

That the composition of the root may be influenced by the scion has been discussed above (p. 86), and, according to Klotz (1927, p. 632), inoculation tests have indicated that seedling trees of sour orange may be slightly more resistant to Pythiacystis gummosis than sour orange used as a stock. This would indicate the lowering of the degree of resistance of the sour stock through the influence of the susceptible scion. If the degree of resistance is due to some structural character, as seems true for varieties resistant to citrus canker (McLean, 1921), it is not probable that any change would occur, since such characters apparently would not ordinarily exhibit stionic influence.

Where the infection or the effect of a disease may be influenced by the vigor of the plant, the stock may be expected to have a marked influence, as the

vigor of the scion is often clearly influenced by that of the stock. It was probably this influence of stock on scion that caused the effects noted by Lee (1921) in his observations on the relation of rootstocks to mottle-leaf.[1] The observations were made with respect to young orchard and nursery trees at Lamao, Philippine Islands, and include the influence of five widely different stocks on numerous scion varieties of different species. A careful examination gave results as shown in table 8.

The trees that were badly mottled were usually small. Lee (1921) stated: "Trees of the Valencia orange or Oneco mandarin, for instance, made a very

TABLE 8

INFLUENCE OF ROOTSTOCK ON SUSCEPTIBILITY OF CITRUS TREES TO MOTTLE-LEAF*

| Rootstock | Total number of trees | Trees affected with mottle-leaf | |
|---|---|---|---|
| | | Number | Per cent |
| Pummelo | 1,145 | 695 | 60.69 |
| Cubuyao | 41 | 14 | 34.14 |
| Sour orange | 95 | 23 | 24.21 |
| Calamondin | 298 | 34 | 11.40 |
| Mandarin | 465 | 22 | 4.73 |

* After Lee (1921).

substantial growth on mandarin orange stock. The same varieties, of the same age, on pummelo stocks of the same age in adjoining rows, were much smaller at the time of the observation and lacked the vigorous appearance of the trees on the other stocks." (See fig. 49.)

The writer has several times observed the tendency of grapefruit stocks to induce mottling of scions of orange varieties in California nurseries, and Fawcett (1936, p. 356) mentions that Rough lemon stocks tend to produce mottling on lemon varieties. Such effects as these may be induced by lack of affinity between stock and scion, or the mottling may result from a variety of causes; but at any rate, what happened was that the stock did influence the scion in its susceptibility to a nutritional disease.

The obscure nature of stionic reactions to disease is well illustrated by investigations in Palestine not many years ago by Reichert (1928, 1930), who described the occurrence of a new citrus disease mainly affecting sweet lime rootstock. As this is the most commonly used rootstock in Palestine, the damage caused was considerable. Later, Reichert and Perlberger (1934) gave the name "Xyloporosis" to the disease and published the results of extensive studies on its cause and control. The disease is characterized by the failure of numerous small areas of the tissue of the stock, just below the bud, to develop normally. This results in the formation of numerous small pits or pores in the wood immediately below the bark (see fig. 50, *A*) and corresponding pro-

[1] The term "mottle-leaf" is used here and in the following paragraph as a general symptom of ill health, without reference to the true cause of the trouble.

trusions or pegs on the inner surface of the bark. The wood of the trunk fails to lignify fully, and the weakened trunk is likely to bend over under the weight of the fruit. The carbohydrates are largely detained in the scion part of the tree, and the overgrowth of the scion at the bud union is usually very marked.

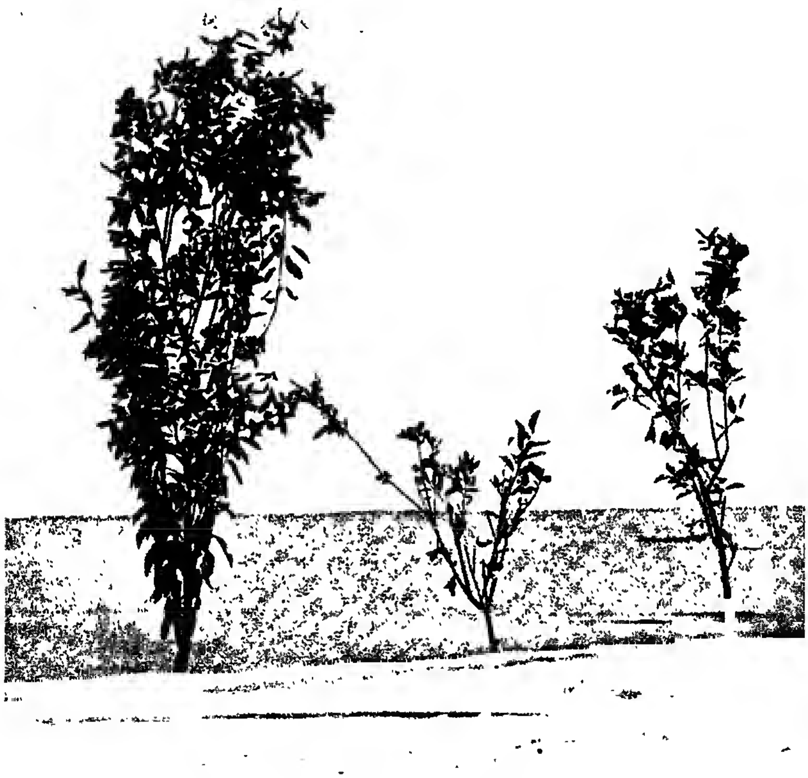


Fig. 49. Stunted growth of scion due to "mottle-leaf-susceptible" stock: *left,* mandarin orange variety on resistant mandarin orange stock; *right,* two trees of the same mandarin orange variety on susceptible pummelo stock. All trees of same age and from adjacent rows. (After Lee, 1921.)

The true cause of the disease has not been definitely determined. Reichert and Perlberger (1934, p. 195) stated: "Only Sweet Lime is susceptible to Xyloporosis, mostly when budded with Shamouti, but the disease also appears on unbudded Sweet Lime especially underneath the limbs on trunks of trees whose central stem has been pruned away. The disease has also been found on Sweet Lime grafted with Sour Lemon, Grapefruit, and Mandarine."

Moreira (1938*a*, 1938*b*), in Brazil, has reported typical symptoms of xyloporosis when the Lima da Pérsia[1] was budded with Laranja Barão (sweet orange). The symptoms of the disease did not become visible for about three years, but 56.9 per cent of the trees died within four years. Moreira interpreted the diseased condition as due to "disharmony" or lack of congeniality between the stock and the scion. He found that the Pêra sweet orange worked on Lima

A B

Fig. 50. Xyloporosis. Trunks of budded trees at region of bud union, with bark removed to show the pore and peg lesions: *A*, lemon on Palestine sweet lime stock, grown in Palestine; *B*, Eureka lemon on sour orange stock grown in California.

da Pérsia did not develop the disease and grew well, a fact apparently indicating that not all sweet oranges react in the same way when propagated on the Lima da Pérsia. Certain diseased trees of the Barão on Lima da Pérsia were top-worked to Lima da Pérsia, and others to Pêra orange. These trees, after a year's growth with the new tops, showed marked indications of recovery. Affected trees were also inarched above the bud union with sour orange seedlings planted at the base of the tree, and are said to have recovered.

In the writer's studies in California, few if any typical cases of xyloporosis have been observed. No very extensive search has been made, but a rather large number of trees have been examined. These have included scions of Owari Satsuma on seedling rootstocks of Duncan grapefruit, Coleman citrange, and African sour; and Eureka and Lisbon lemon scions on stocks of

[1] Lima da Pérsia is the name used in Brazil for a certain sweet lime; this is not the acid lime known in the United States as the Persian or Tahiti lime.

variant types of seedling sour orange, lemon, etc.—stionic combinations that commonly collapse and die within a few years after budding, supposedly owing to lack of congeniality between stock and scion. None of these trees, however, have exhibited symptoms of xyloporosis. A number of trees examined have shown excessive overgrowth or swelling immediately above the bud union, a condition occurring regularly in the citron varieties Corsican and Diamante budded on sour orange stocks, but on none of these severely dwarfed eight- and ten-year-old trees have clear indications of xyloporosis been found. One that, so far as could be judged, did exhibit the typical "pore and peg" symptoms of xyloporosis, a seven-year-old tree of Eureka lemon on sour orange stock (see fig. 50, *B*), was found at Escondido, California. Slight indications of the "pore and peg" lesions similar to those of xyloporosis have also been observed on the sour orange stock of a seventeen-year-old Marsh grapefruit tree at Fontana, California. The stock of this tree was evidently a poor variant of sour orange, as the scion was markedly swollen at the union. Dr. H. S. Fawcett has informed the writer (in conversation) that he has observed symptoms similar to those of xyloporosis on stocks of sour orange and sweet orange budded to Willow-Leaf mandarin growing in orchards of the California Citrus Experiment Station at Riverside.

Until the fundamental cause of xyloporosis has been determined, definite recommendations for its control cannot be made. It seems clear, however, that where the disease is found to be associated with certain stock-scion combinations, these should be avoided in making propagations.

In Italy and other places where mal secco (*Deuterophoma tracheiphila* Petri) is prevalent, the discovery of resistant varieties is an important consideration. Ruggieri (1937) has discussed the high resistance shown by the "Monachello" lemon, and propagations have been made with it and various stocks in testing the possibilities of reconstructing lemon trees attacked by the disease.

The tristeza disease of sour orange rootstocks has been shown to exhibit a complex and interesting series of stionic reactions, on which an interpretation of the probable cause of the malady has been based. (For a description of the disease see chap. xi.) The trouble was first observed in South Africa about 1910, when it was found that varieties of the sweet orange on sour orange rootstocks soon became sickly and died (Davis, 1924; Webber, 1925). A malady showing the same general symptoms was next observed in Java in 1928 (Toxopeus, 1936, 1937); and a few years later, about 1931, it appeared in Argentina, and about 1937 in Brazil (Bitancourt, 1940–1941). As the cause of the disease has not been definitely determined, its identity in the different countries mentioned is not conclusively proved. The following are some of the peculiar stionic reactions observed in the susceptibility to tristeza.

Varieties of the sweet orange, mandarin orange, and grapefruit on sour orange rootstock, if grown in localities where the disease occurs, soon wither and die, or certain trees may occasionally live for some years but remain dwarfed and worthless (Davis, 1924; Webber, 1925; Powell, 1930; Toxopeus, 1936, 1937; Marloth, 1938; Bitancourt, 1940–1941; Moreira, 1942).

Varieties of lemon on sour orange rootstocks grow normally and do not seem to be affected by the disease (Davis, 1924; Webber, 1925; Powell, 1930; Bitancourt, 1940–1941; Moreira, 1942).

Diseased trees of sweet orange on sour orange stocks inarch-grafted above the bud union with seedlings of Rough lemon or Japanese citron[1] recover, but the original sour orange rootstock dies (Powell, 1930; Toxopeus, 1937; Marloth, 1938).

If both sweet orange and Japanese citron are budded into the same sour orange stock, the tree soon dies (Toxopeus, 1937).

A diseased tree of sweet orange on sour orange stock, if the decline has not progressed too far, can be top-worked with lemon scions, and as soon as the lemon top develops and the foliage of the sweet orange is removed the tree recovers (Bitancourt, 1940–1941; Moreira, 1942; Camp, in correspondence,[2] and 1945, *b*).

A sprout that gets started from the roots of a diseased tree of sweet orange on sour will grow into a normal tree, but the original tree will die (Marloth, 1938; Camp, in correspondence cited above).

Toxopeus (1937), in a series of experiments, employed sweet orange, sour orange, and Japanese citron in each of the twelve possible combinations as scion, stock, and interstock. Of these he found that only three combinations were affected and died—those in which the scion was sweet orange and the stock or the interstock was sour orange.

Apparently, most citrus species when grown as seedlings exhibit no detectable indications of the tristeza disease. This has been reported to be true of seedlings of the sweet orange, sour orange, Rough lemon, sweet lime, and Japanese citron. The list should also include the mandarin orange, many healthy old seedlings of which the writer examined in South Africa, and probably also the grapefruit.

Following is a list of the various citrus combinations that have been reported as susceptible or resistant to tristeza. The numbers in parentheses following each combination indicate the authority cited for the statement.[3]

[1] The identity of the variety designated "Japansche Citroen" in Java is not definitely known. Ochse (1931) gives a good colored illustration of it (pl. 48) under the title "*Citrus nobilis* Lour., hybr. *Japansche Citroen, Dutch*." The Japansche Citroen, he stated further (1931, p. 121), "has got its name because, on a shallow view, it seems to be a cross between *Citrus nobilis*, Lour., var. and *Citrus Limonia*, Osbeck, var. One has given the name *Japansche Citroen* (i.e., *Japanese Citron*) to the offspring of a so-called sour Japanese *Mandarine*, found in Batoe." Ochse (1931, p. 121) thinks it is to be considered a form of Bonavia's Jambhiri group (Bonavia, 1888–1890, p. 60). Definite identity with forms cultivated in the United States cannot now be established, but Bonavia (1888–1890, pp. 16, 38, 60) mentions two varieties of fruit of the Jambhiri group, one with yellow exterior like the lemon and the other with red exterior like the orange. Such statements and the brief descriptions given by Bonavia seem to suggest identity with the mandarin-lime varieties Kusaie and Rangpur grown in the United States (see this work, Vol. I, pp. 626 and 628). Thus the "Japansche Citroen" is probably to be considered similar to the Rangpur mandarin-lime.

[2] Dr. A. F. Camp, Vice-Director in Charge, Florida Citrus Experiment Station, Lake Alfred, Florida. Letter of March 9, 1943, to Dr. L. D. Batchelor. Cited with permission.

[3] 1, Davis (1924); 2, Webber (1925); 3, Powell (1930); 4, Toxopeus (1937); 5, Marloth (1938); 6, Bitancourt (1940–1941); 7, Moreira (1942); 8, Camp (in correspondence; see preceding footnote); 9, Webber (1943*a*, 1943*b*).

### Susceptible Variety Combinations

Sweet orange varieties on sour orange stocks (1, 2, 3, 4, 5, 6, 7, 8)
Mandarin and tangerine varieties on sour orange stocks (1, 2, 3, 5, 7, 8)
Grapefruit varieties on sour orange stocks (3, 5?, 6?, 7)
Thornton tangelo on sour orange stocks (7)
Sweet orange on Sampson tangelo stock (5?)
Sweet orange on Lima da Pérsia (sweet lime) stocks (7?)
Limoeiro galego (Mexican lime) on sour orange stocks (7)

### Resistant Variety Combinations

Sweet orange on sweet orange stocks (6)
Sweet orange on grapefruit (pomelo) stocks (6)
Sweet orange on sweet lime (Lima da Pérsia) (6)
Sweet orange on Rough lemon (1, 2, 3, 5, 6, 7, 8, 9)
Sweet orange on trifoliate orange (6, 8)
Sweet orange on Rangpur lime (Limoeiro cravo) (7)
Sweet orange on Limoeiro gigante (?) (7)
Sweet orange on Japanese citron (4)
Sweet orange on laranjeira caipira (7)
Lemon varieties on sour orange stocks (1, 2, 3, 5, 6, 7, 8, 9)
Kumquat on sour orange stocks (6)
Grapefruit on sour orange stocks (5?—some success)
Sour orange on sweet orange stocks (4)
Tangerine on trifoliate orange stocks (6)
Sampson tangelo on sour orange stocks (7)

## THE QUESTION OF THE CAUSE OF TRISTEZA: IS IT A VIRUS DISEASE?

Many causes have been advanced for tristeza, including attack by a bacterial or parasitic fungus, incompatibility of stock and scion, soil depletion, lack of some important minor element or elements, and stress of severe weather changes. None of these, as pointed out by the writer (Webber, 1943*a*, 1943*b*), appears to conform to the peculiar manifestations of the disease and its apparent spread from country to country. No parasitic fungus or bacterium has yet been found that could be considered a causal agent, and the stionic reactions exhibited by the disease seem definitely to preclude such a cause. Soil depletion, lack of some element of nutrition, or stress of climatic influences seem also to be precluded as causal agents by the extremely wide range of conditions under which the disease occurs and its sequence of spread from country to country. Incompatibility of stock and scion may also be disregarded as a causal agent, as the same combinations in the same and many other locations have been successful for many years without showing the disease.

The unique theory advanced by Toxopeus (1937), that some substance developed in the sweet orange top is lethal to the sour orange root, does not explain the cause until the conditions are explained under which such a substance is developed (Webber, 1943*a*, 1943*b*). If it is some constituent developed in the sweet orange top that causes the death of the sour stocks, it must be something foreign to the normal metabolism of the sweet orange, that is, something acquired in the locality where the trouble occurs. The only material

that could be acquired by the plant—so far as we now know disease-producing agents—which could be expected to give the results indicated by the stionic reactions observed, would be some virus. A virus might be carried to the sweet orange by an unknown vector to which the sour orange is normally repellent—a virus not noticeable in the sweet orange, but lethal to the sour orange root when introduced into that species through the sweet orange scion.

Bitancourt and Fawcett (Bitancourt, 1940–1941, p. 287) suggested that the disease might be caused by a virus, but gave an interpretation inadequate to explain all the known reactions. In an analysis of the character and spread of the disease and the peculiar reactions exhibited by different species used as scions, rootstocks, and interstocks, as outlined above, the writer (Webber, 1943*a*, p. 166; 1943*b*, p. 353) concluded that the tristeza disease seemed most nearly to conform to the peculiarities exhibited by a virus disease. He wrote (Webber, 1943*a*, p. 166):

"It seems to the writer more plausible, therefore, to assume that the disease is due to a virus, and then the simple assumption *that the foliage of the sour orange and the lemon produces regularly and normally some product of metabolism that inhibits the action and development of the virus* would explain all the difficulties now experienced in attributing the disease to a virus.

"If this is assumed as correct, then sour on sweet would be healthy, while sweet on sour would die, which is the case; also sprouts from the sour stock if they developed foliage would be expected to grow without injury, which according to both Marloth and Camp is true; also if trees of sweet on sour are top-worked to lemon before they decline too far, then as soon as the sweet foliage is removed and the lemon foliage develops the tree would be expected to recover, as it is known to do; also trees of sweet on sour inarched with resistant Rough lemon or 'Japanese citron' would be expected to recover, and they do; but the original sour stock still supplied by sweet-orange foliage should die, and it does. Wherever the sweet-orange, mandarin, or grapefruit foliage forms the top, the virus would be expected to continue its activity, and apparently this is the case."

The true nature of the tristeza disease has not been fully demonstrated, but what has been learned about susceptible and resistant scion and stock varieties will enable growers to choose resistant combinations and perhaps to recover diseased trees. (See Fawcett and Klotz, this volume, chap. xi; Bitancourt, 1943.)[1] It should be stated, however, that experience with the disease is still very limited, and some of the observations on degree of resistance may, on further trial, prove to be erroneous.

In view of the great economic importance of the resistance of both stock and scion varieties to disease, the stionic reactions of these characters are significant and are as yet imperfectly known. (Consult chap. xi, p. 584, below, and Fawcett, 1936.)

[1] The author of this chapter died before experimental evidence was obtained (Fawcett and Wallace, 1946; Meneghini, 1946; and Oberholzer, 1947) showing that both orange-tree quick decline in California and tristeza in South Africa and Brazil are apparently virus diseases.—L. D. B.

## GENERAL CHARACTERS OF CITRUS ROOTSTOCKS

### BEHAVIOR IN THE NURSERY

Many times, rootstocks have been chosen because they were easy to handle in the nursery, owing to such factors as availability of seeds, ease of germination, rapidity of growth and quickness of attaining the size for budding, ease of budding, and shortness of time required for budlings to reach salable size. In early days in California the China lemon, a variety of citron, was much used because of its excellent nursery characters; but it proved, in time, an unsatisfactory rootstock. Simons, Clavell, and Serrano (1939, p. 86) have directed attention recently to the superior nursery performance of Puerto Rico grapefruit and Davao lemon, and the inferiority of Cleopatra mandarin. Of these three varieties the only one that is known to be a valuable stock is the Cleopatra. (Compare also Richards, 1938.)

It is of some importance that a rootstock should possess good nursery characters, but it must be clearly recognized that certain poor nursery characters may be wholly overshadowed in importance by good orchard response, as exhibited by the longevity of the trees and the production of large fruit yields over many years. In the nursery each tree uses a space of only 3 to 6 sq. ft. for about two years, while in the orchard each tree uses a space of 400 to 500 sq. ft. for a productive period of forty to sixty years. The little extra trouble and expense required in the nursery to grow even the slowest and most difficult rootstocks is thus of very minor importance.

### THE SOUR ORANGES

*Citrus Aurantium* Linnaeus

The sour orange grows readily from seeds, which are more resistant to injury from drying out than are seeds of many *Citrus* species. It is a vigorous grower in the nursery, developing mainly a strong single trunk which facilitates easy budding. It commonly produces from 75 to 80 per cent of nucellar embryos and thus requires the elimination of only about 25 per cent of the population to remove the variants (Webber, 1931, 1932*b*, 1932*e*). It may be grown from cuttings, but is more difficult to root than Rough lemon or sweet orange. It is more cold-resistant than any stock commonly used, other than the trifoliate orange. When frozen down, it sprouts readily from the base of the trunk.

The sour orange is very resistant to gummosis diseases such as foot rot, shell bark, scaly bark, and the like. Klotz and Fawcett (1930, p. 421), after conducting extensive inoculation experiments, concluded: "The long-observed and acclaimed resistance of sour orange has been substantiated. Here again the seedling form of the variety shows a greater resistance than the budded, in fact so great a resistance that for all practical purposes it may be considered to be immune." It is possible that the resistance may be in some degree influenced by the scion variety used with it. Provan (1933) found in Australia that sour rootstocks budded to lemon or Washington Navel were much more susceptible to collar rot than those budded to Valencia orange. The sour orange

is susceptible to scab (verrucosis), which sometimes causes serious injury in humid climates. According to Fawcett (1936, p. 308), it is particularly susceptible to mal secco, a much-dreaded disease which is causing serious injury in Italy and Sicily. In sections where this disease occurs, it may be necessary to use some other, more resistant stock. The sour orange is very susceptible to tristeza (see p. 100) when the scion variety is sweet orange, mandarin orange, or grapefruit. It is also susceptible to orange-tree quick decline when the scion variety is sweet orange.

Fig. 51. Comparative growth of Valencia orange in the light sandy soil of central Florida, on sour orange stocks (*left*) and on Rough lemon stocks (*right*). Trees thirteen years old. (Such marked differences do not occur on sandy soils in California.)

The bud unions on good sour orange varieties are nearly normal with sweet orange, mandarin, and tangerine oranges, and grapefruit varieties, but rather commonly show a strong bud overgrowth with most varieties of lemons, limes, and citrons, indicating lack of congeniality. The Lisbon lemon on certain selected strains of sour, however, apparently gives a fully congenial reaction.

The sour orange has commonly been considered to be best adapted to growth on low, moist, and fairly heavy soils. It is on such soils that the wild natural groves of sour orange in Florida became established, and on which it has since proved to be the most successful rootstock. On the very light sandy soils of the so-called ridge section of central peninsular Florida it has been a failure as a rootstock, and the difference in tree size of varieties on sour orange stocks, in comparison, particularly, with those on Rough lemon, is frequently very marked (fig. 51).

In California, however, the sour, especially with lemon scions, has apparently been equally successful on light sandy soils (as in the Upland district). In the California rootstock experiments, sour stock with lemon scions gave

better results on a fairly light sandy soil at Riverside than on a much heavier loam soil at Fillmore (see chap. iii, p. 210).

The explanation of these different reactions is probably to be sought in the different climatic and soil conditions of the two states as they react on the deep-rooted sour orange. In California, where alkali in subsoils and underground waters is frequently a serious problem, a deep-rooted plant like the sour orange may be seriously injured. This condition is most likely to occur on low, heavy lands where drainage is poor, and less likely on light sandy soils which permit the free passage of irrigation water and thorough drainage (compare chap. iii, p. 172). In Florida, on the contrary, the accumulation of alkali in injurious concentration is of rare occurrence, and the limited root system of the sour orange apparently finds more congenial conditions in the low, rather moist, and heavier soils than on the sterile sandy areas of higher lands.

Fig. 52. Nine-year-old Washington Navel orange on sour orange rootstock. Note tendency to form several taproots and few spreading lateral roots. (After Mills, 1902.)

The sour orange normally develops one or more taproots (fig. 52), which grow to a considerable depth, but lateral root development is more limited than in Rough lemon, sweet orange, or grapefruit. The taproots of sour orange rootstocks which are cut back in transplanting commonly branch and form a group of small taproots. Halma (1934) found that in one mature Eureka lemon orchard the average number per tree of main roots, of sixty-four trees on sour stocks, was fifteen, of which 65 per cent were typical taproots, whereas the root systems of a similar number of trees on sweet stocks were practically devoid of taproots.

Deep root penetration on deep soils renders the sour stock in some degree resistant to the effects of drought. Hume (1926, p. 201) states: "... it has been observed repeatedly in Florida that both nursery and grove trees on sour-orange stock suffer much less in periods of protracted drought under identical conditions than do those on rough-lemon roots." Evans (1922), however, states that in Dade County, Florida, grove trees on grapefruit and sour orange stock may be actually dying from drought when trees on Rough lemon right across

Fig. 53. Comparative growth of Mexican lime on sweet orange stock (*left*) and on sour orange stock (*right*). Trees three years old.

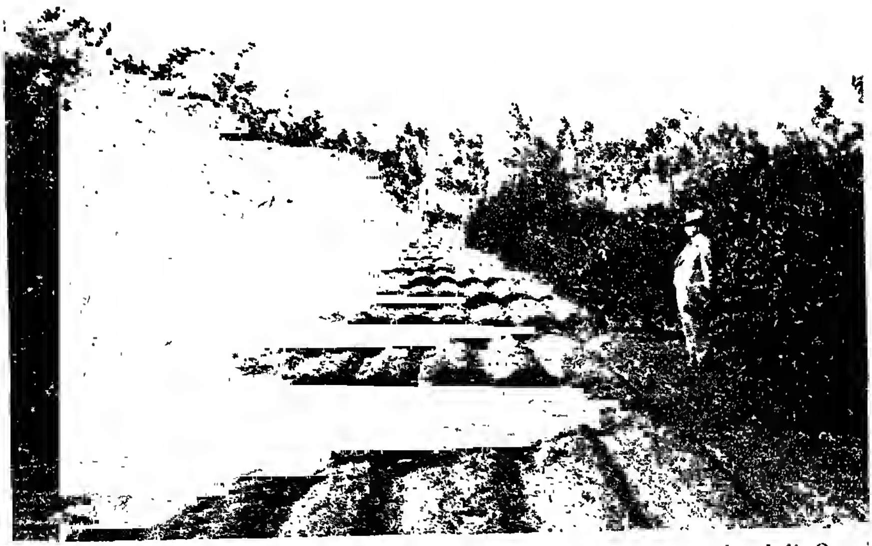


Fig. 54. Poor growth of Satsuma orange on African sour orange stocks: *left*, Owari Satsuma on Sampson tangelo stock; *right*, Owari Satsuma on African sour orange stock. All trees ten years old. Note small size of trees on African sour stock, and broken stand caused by early death of two of the five trees in this plot. The trees on Sampson tangelo are about the same size as those on sweet orange stocks near by in the same field.

the road remain in excellent condition. This effect in Dade County is probably due to the closeness of the rock to the surface, which prevents deep root penetration.

The sour orange, because of its tendency to develop taproots, has also been used extensively in the West Indies as a rootstock for the lime. Such trees are reported by some growers to withstand hurricane injury better than lime on its own roots. Fennah (1937), however, in a study of the root systems of budded limes on St. Lucia Island, found that sour orange seedlings in the nursery all had taproots; but that of 24 orchard trees of lime budded on sour orange at three years old, only 3 had living taproots; and that of 110 five-year-old plants, only 3 had living taproots, the root systems of which were almost wholly horizontal. Fennah was inclined to explain this condition as due probably to early damage caused by the citrus weevil (*Diaprepes* spp.), and to injury in transplantation.

Trees of most citrus varieties on the sour orange are, in general, slightly smaller than those on sweet orange (fig. 53) or Rough lemon. They would be classed as low standard in size and should probably be planted somewhat closer together than trees of the same variety on sweet orange or Rough lemon stocks.

Fruits of the sweet orange, tangerine, and grapefruit produced on sour orange stocks tend to be smooth, thin-skinned, juicy, excellent in quality, and to hold up well without deterioration.

Harding, Winston, and Fisher (1940), Harding (1940), Fudge and Fehmerling (1940), and Camp (1941) have all given data showing that fruits of sweet orange varieties grown in Florida on sour orange rootstocks are normally richer in degree of acidity, amount of sugars, ratio of sugars to acids, and comparative juice content than the same varieties grown on Rough lemon rootstocks. However, it must be remembered that in the light sandy soils of the warm ridge section of Florida the sour orange is entirely unsatisfactory as a rootstock, whereas the Rough lemon gives fairly good yields of acceptable fruit. As to the use of sour orange in Florida, Camp (1945, p. 27) states: "It is not adapted to very light sandy soils but will withstand a great deal of waterlogging of the soil and is generally recommended for heavy soils, including the best grades of flatwoods, hammock, muck, and other soils which are subjected to occasional flooding. It is a particularly desirable stock for tangerines, Temples, tangelos, and other similar specialty fruits because of the high quality of fruit produced."

Attention should be directed to the fact that in the United States the failure of the Satsuma orange on sour orange stocks has frequently been noted. In the rootstock tests of the California Citrus Experiment Station, at Riverside, the Owari Satsuma responded differently on different varieties of sour orange. On the sour orange cultivated under the name African the trees were considerably dwarfed, and at the end of ten years many had died (fig. 54). On the Brazilian sour, however, the trees grew normally and were still in good health at the end of ten years in the orchard, when the experiment was discontinued. In this experiment a similar failure of the Owari Satsuma trees

was noted on stocks of the Duncan grapefruit and the Coleman citrange, where no contributory disease could be found (see also chap. iii, pp. 195–198). Many such stock failures remain as yet unexplained.

According to Thos. W. Brown (1924), the sour orange, notwithstanding minor defects, is the safest stock to use for the propagation of most kinds of citrus cultivated in Egypt. El Sawy (1936), writing twelve years later, stated that the sour orange was the most widely used stock in Egypt, but that it was inferior to lime or Rough lemon on sandy soils. Weston (1932*a*, 1932*b*) recommended the sour orange as best suited to conditions in the Island of Cyprus. Pope (1934) found the sour orange to be one of the best rootstocks for use in Hawaii; and Schultz (1939) concluded that the sour orange ordinarily is the best rootstock for citrus in the districts around Tucumán, Argentina, whether grown under irrigation or without it. In the Mildura irrigation district of Australia, Provan and Cole (1944) reported the size, yield, and health of Washington Navel and Valencia orange trees on sour orange stocks to be inferior to those on sweet orange or Rough lemon.

It is interesting to note that Konstantinov (1940) has stated that in Kisyl-Atrek, on the coast of the Caspian Sea, strains of the sour orange have been selected which are not affected by salinity.

The evidence available indicates that the sour orange is probably the most successful stock to use for varieties of sweet orange, grapefruit, and tangerine, when the trees are to be grown in regions with humid climate, or on heavy soils. It is also probably the most satisfactory stock to use on heavy soils in all arid regions when budded to grapefruit, and must, in general, be considered as adapted to widely varying conditions. It is not a good stock for the Satsuma and commonly is not satisfactory for lemon varieties, though up to the present it has been used extensively thus, in both Italy and California. As a stock for varieties of the sweet orange, mandarin orange, and grapefruit it has been a failure in South Africa and Java; and recent studies in Argentina and Brazil indicate that it will also have to be abandoned as a stock for such varieties in South America. The tristeza disease, which apparently causes its failure in these countries (see p. 100), may spread to other countries.[1]

It must not be forgotten that there are many varieties and forms of the sour orange, and that while some of them are failures as stocks, others are very satisfactory. In the California Citrus Experiment Station tests the sour orange variety known as the Brazilian has, in general, given the most satisfactory results, but the varieties Standard and Rubidoux have been nearly as satisfactory. The African and many variant types, however, are much less satisfactory. (See chap. iii.)

## THE SWEET ORANGES

*Citrus sinensis* (Linn.) Osbeck

The sweet orange grows readily from seeds, but the seeds are easily injured by drying out and must therefore be handled carefully. Seedlings grow more

[1] The rapid spread of orange-tree quick decline in California, and the practical abandonment of the sour orange rootstock by the nurserymen of the state, occurred after the death of the author of this chapter.—L. D. B.

slowly, when young, than those of the sour orange, and produce lower-branched, bushy trunks which are more difficult to handle in budding. They require more pruning to shape them than seedlings of the sour orange or Rough lemon. Buds, after insertion, grow rapidly and produce large budlings. The sweet orange may be grown from cuttings more easily than the sour orange, but not so easily as the Rough lemon. Good stock varieties produce ordinarily from 70 to 90 per cent of nucellar embryos, and the elimination of approximately 10 to 30 per cent of the small seedlings in any population is accordingly necessary to remove the variants. The sweet orange is only median in cold resistance, but is slightly hardier than the Rough lemon. When frozen to the ground, it sprouts readily from the base of the trunk. It commonly gives normal bud unions with varieties of the sweet orange, mandarin, tangerine, grapefruit, lemon, and lime.

Experimental inoculations by Klotz and Fawcett (1930) indicated that the sweet orange was less susceptible to gummosis than the lemon, and was of about the same susceptibility as, or only slightly less than, the grapefruit. It was, however, much more susceptible than the mandarin orange and, especially, the sour orange. Considerable variation in susceptibility is shown by different varieties of sweet orange, and the most resistant types should be tested as rootstocks. While the sweet orange is susceptible to the various gummosis diseases, as well as to scaly bark, it is resistant to sour orange scab of verrucosis, tristeza, orange-tree quick decline, and mal secco.

The sweet orange grows well on fairly heavy soils, but is best adapted to growth on rich sandy loams. It is one of the best stocks available for sandy soils and is grown to some extent in moderately humid countries on well-drained, light sandy soils. Its use should be followed by regular inspections and prompt treatment if gummosis diseases appear. It does not commonly develop a well-differentiated taproot and usually is moderately shallow-rooted. It does, however, develop an abundant system of lateral roots (fig. 55). Mills (1902, p. 12) stated that "the sweet orange is a surface-growing stock which has few or no deeply-penetrating roots."

Stocks of the sweet orange produce large, vigorous trees of standard size in combination with all commercial citrus varieties. Fruits on sweet stocks mature at the normal season for the variety; they are thin-skinned, juicy, and of high quality, and hold up well in all characters to the extreme end of the shipping season. Wherever sweet orange stock can be used with safety, in view of its susceptibility to gummosis diseases, it may be considered one of the best standard stocks for fruit varieties of the sweet orange, mandarin, grapefruit, lemon, and lime.

In California the sweet orange is now more largely used in new plantings than any other rootstock; in no other place is it at present used to any appreciable extent. In rootstock discussions originating elsewhere the statement is usually made that it is considered unsatisfactory because of its susceptibility to gummosis diseases. Of its use in Florida, Camp (1945, p. 27) states: "The quality of fruit borne on trees budded on this stock is excellent but the production does not compare favorably with that on rough lemon,

particularly in young trees, nor does its resistance to drouth on light sandy soils compare favorably. It is not used on heavy soils because of its susceptibility to foot rot. It is used to some extent on intermediate soils as a stock for specialty fruits but is generally considered inferior in this regard to sour orange stock."


Fig. 55. Root systems of rootstock species: *left*, sweet orange, ten years after planting; *right*, grapefruit, seven years after planting. Note the absence of taproots and abundance of lateral roots. (After Mills, 1902.)

In the Irymple rootstock experiment in Australia, begun in 1934, sweet orange stocks have been found by Provan and Cole (1944) to produce during a ten-year period larger, healthier trees, and larger yields, than comparable trees on sour orange and Rough lemon stocks. The total average yield per tree for the five-year period from 1939 to 1943 inclusive was as follows:

| | *Average yield per tree, in pounds* | | |
|---|---|---|---|
| | *Sweet stock* | *Sour stock* | *Rough lemon stock* |
| Washington Navel | 696 | 575 | 682 |
| Valencia | 505 | 418 | 426 |

The comparative size of the trees of Washington Navel on the three rootstocks in the eighth year after planting is shown by the average trunk circumference six inches above the bud union. These were: sweet, 40.83 cm.; sour, 33.21 cm.; and Rough lemon, 35.72 cm. The sizes for the Valencia on the three different stocks were stated to be about the same. Marloth (1938), in discussing rootstocks for South Africa, wrote: "Considering the good showing made by the few orchards in the country on sweet orange stock, it is surprising that

Fig. 56. Comparative root systems: *left*, Koethen sweet orange stock, and, *right*, Rough lemon stock, both with Satsuma orange scions. Trees ten years old.

more use of this stock has not been made. On one large property where a very high loss of trees on rough lemon stock from 'Dry Root Rot' has been experienced, two 1,000-tree blocks of Valencia trees on sweet orange stock, 18 years old, have had relatively few losses."

All the evidence available indicates that the sweet orange is one of the best stocks, if not the best, to use with varieties of lemons, oranges, grapefruits, and mandarins in those regions where it may safely be grown. In the rootstock experiments of the California Citrus Experiment Station the sweet orange has proved one of the best stocks for the Satsuma orange. In this combination it develops a very vigorous root system, which is in general more extensive than that of the Rough lemon with Satsuma (fig. 56)—an interesting stionic reaction, since for most scion varieties the opposite would probably be true.

The experience of growers in California and the results of limited tests at the California Citrus Experiment Station indicate that the sweet orange is one of the best rootstocks for varieties of the lime (see fig. 53; also Vol. I, p. 617, and Webber, 1932*c*).

Because of its susceptibility to gummosis (Fawcett, 1936, p. 177) the sweet orange probably cannot be much used as a stock in humid regions. In arid regions, however, and in semiarid regions such as California, Spain, Italy, Palestine, and parts of Africa and Australia, it may be used successfully under proper hygienic culture. Wherever sweet orange stocks are used, the trees must be planted high, so that the buttresses of the crown roots show at the soil surface, and regular inspections should be made to discover and treat promptly such infections as may occur. Even in arid regions sweet stocks probably should not be used on heavy soils.

### THE MANDARIN ORANGES

*Citrus reticulata* Blanco

Mandarin and tangerine orange varieties are little used as rootstocks, although in the Swatow section of China, famous for the fine quality of its oranges, they are used almost exclusively (Lee, 1921). T. Tanaka (1929*a*) states that the Cleopatra is identical with the Ponki, a variety of Chinese origin, used extensively as a rootstock in China.

Most mandarin varieties exhibit a high percentage of nucellar embryony, ranging usually from 80 to 100 per cent (see Frost, this work, Vol. I, p. 794), and thus ordinarily require little roguing to obtain fairly uniform lots of seedlings. They are commonly frost-hardy, rather resistant to diseases such as gummosis, and very resistant to verrucosis or scab. In general they produce standard or only slightly smaller than standard trees of varieties propagated on them. The principal objection to their use is the slow development of seedlings and young budlings.

One mandarin variety, the Cleopatra, is employed to some extent in Florida, where it was apparently first introduced as a rootstock by the Reasoner Brothers, of the Royal Palm Nurseries at Oneco. The use of this variety has extended gradually in Florida, and it now holds about third place in popularity in that state. It is said to be hardy and drought-resistant, to give good-quality fruit, and to be adapted to light sandy soils (Skinner, 1924). Of its use in Florida, Camp (1945, p. 29) wrote: "It is a good grower, makes a good nursery tree, both as to union and growth, and seems to be well adapted to the light soils, but has a tendency to make tops budded on it slow in coming into bearing."

The Cleopatra mandarin has the disadvantage in the nursery of growing slowly and requiring more time than sour or sweet orange to reach good budding size. Seedlings of the same age in the nursery of the California Citrus Experiment Station showed, at budding time, average trunk circumferences as follows: Cleopatra mandarin, 4.28 cm.; Brazilian sour orange, 5.44 cm.; Bessie sweet orange, 5.82 cm. Rough lemon seedlings one year younger averaged 6.38 cm. According to Vosbury and Robinson (1929), the Cleopatra has the advantage of high resistance to citrus scab and foot rot; it is also fairly cold-resistant. Klotz and Fawcett (1930) report that Willow-Leaf and Cleopatra varieties of the mandarin showed some resistance to Pythiacystis gummosis.

Jefferies (1930, p. 109) states that trees budded on Cleopatra mandarin tend to make a denser top than those budded on either sweet orange or Rough lemon.

In tests at the California Citrus Experiment Station, the Cleopatra was so slow in development that during the first five-year fruiting period it ranked very low in yield. In the course of the next five-year period, however, the comparative yields greatly improved, as did the comparative yields from other mandarin orange stocks (see chap. iii, p. 196), and it now seems evident that the Cleopatra may be considered as ranking among the promising stocks, to insure long life and satisfactory fruiting, especially for lemon varieties. It may not stand out as a superior stock for general use in California, but it seems to merit commercial trial.

Some other mandarin varieties have been tested as rootstocks (see chap. iii), and in South Africa a tangerine similar to the Dancy has been successfully employed as a stock for tangerines (Davis, 1924). A mandarin variety known as Sunki (probably the Suen Kat of Swatow), similar to the Cleopatra, is reported (Tanaka and Tanaka, 1932; Y. Tanaka, 1931) as being used in Taiwan (Formosa) and on the adjacent coast of China. It is said to be a semidwarfing, short-lived stock. T. Tanaka (1929*a*), in discussing the very superior quality of the Ponkan and Tonkan mandarins in China and Formosa, indicates that this may be due in part to their propagation on Sunki and Ponki mandarin rootstocks. It is evident that such mandarin rootstocks should be more thoroughly tested in California and Florida, especially in combination with the best fruit varieties of the mandarin. Dr. W. T. Swingle has informed the writer in conversation that the Ponkan in Florida gave poor results on all ordinary stocks.

## THE GRAPEFRUITS

*Citrus paradisi* Macfadyen

The grapefruit grows readily from seeds, which are large and easily injured by drying out. In seedbeds the young plants are very likely to give trouble by gumming and by blooming prematurely, sometimes even setting fruits when only a few inches high. Grapefruit grows vigorously in the nursery and, like the sweet orange, is inclined to branch rather low. It is easy to bud and easy to handle in the nursery.

Different varieties of the grapefruit apparently vary a good deal in the percentage of nucellar embryos formed, the recorded data varying from 26 to 96 per cent. (See Vol. I, p. 794.) Most varieties that are likely to be used in the United States may be considered to range commonly between 70 and 90 per cent nucellar-embryonic. Seedlings thus reproduce moderately true to type, and the elimination of the small off-type seedlings in the nursery, to remove the variants, requires the destruction of, approximately, no more than 20 to 30 per cent of the population.

The grapefruit is slightly less cold-resistant than the sweet orange and exhibits practically the same resistance to gummosis diseases (Klotz and Fawcett, 1930). It shows a strong tendency to develop mottle-leaf in the

nursery (Lee, 1921), and trees budded on this stock also show a strong disposition toward "frenching" or mottling (Hume, 1926). This has frequently been noted also in California nurseries.

The grapefruit develops an excellent root system (fig. 18, p. 35), which Mills (1902) found to spread more widely than that of the sweet or the sour orange. It is apparently best adapted to growth in heavy or loamy soils rich in humus and is poorly adapted to light sandy soils. Most citrus varieties

Fig. 57. Effect of rootstock on scion. Eureka lemon on Sampson tangelo (*left*) and on Duncan grapefruit (*right*). Trees six years old. California Citrus Experiment Station, Riverside.

on grapefruit stocks show an overgrowth of the stock at the bud union (see figs. 38 and 42, above), which with some scion varieties is very pronounced; the trees produced, however, are commonly of about standard size.

Grapefruit stock is usually considered to produce fruit of excellent size, grade, and quality, but to require especially liberal fertilization and careful culture to insure a successful crop.

From time to time the use of grapefruit stock has been recommended both in California and in Florida, but it has nowhere, as yet, come into general use. It has sometimes been recommended as an especially good rootstock for lemons, but in the comparative trials at the California Citrus Experiment Station it has not been outstanding for lemons or any other of the citrus fruits (see chap. iii). In these experiments, seedlings of the Duncan grapefruit, a variety noted for the large size and great age of the parent seedling of the variety (see Vol. I, pp. 27 and 573), were used as a trial stock. When it was thus used with varieties of sweet orange, lemon, grapefruit, or Satsuma, the trees on it never exceeded about medium in size or yield; and all the trees

of Satsuma on Duncan died within a few years. The result was probably most satisfactory with varieties of the lemon (fig. 57); but, even then, Duncan grapefruit was inferior to other grapefruit stocks and much inferior to sweet orange stocks. The foregoing is emphasized as indicating that the size to which a seedling rootstock variety grows and the length of its life cannot be taken as criteria of its value as a rootstock for other varieties.

Writing on the use of grapefruit stock in Florida, Camp (1945, p. 29) stated: "In many cases on lighter soils it has proved unsatisfactory as a stock due to difficulty in getting trees budded thereon to bear properly. On the heavier soils this may be overcome, at least partially, by increased fertilization but on light soils this has not been very effective. It is less cold resistant than sour or sweet orange."

Simons, Clavell, and Serrano (1939) found, in Puerto Rico, that Duncan grapefruit on a native grapefruit stock gave better yields in the early fruiting years than comparable trees on Rough lemon, sweet orange, or sour orange.

Our present knowledge indicates that rarely, if at all, have grapefruit rootstocks given results as generally satisfactory as either sour orange or sweet orange. It would thus seem that grapefruit should be used with caution in any locality until its adaptability has been demonstrated. As a grapefruit rootstock, C.E.S. No. 343, has given fairly good results with Eureka lemon scions, it is not improbable that some satisfactory variety of grapefruit rootstock may ultimately be found.

## THE PUMMELOS OR SHADDOCKS

*Citrus grandis* (Linn.) Osbeck

The pummelo or shaddock corresponds very closely, in its nursery character, to the grapefruit, but differs from it in the important factor that, so far as is known, most pummelo varieties are monembryonic and thus supposedly develop few if any nucellar embryonic seedlings (Toxopeus, 1930; Torres, 1936). Some varieties usually classed as pummelos, however, exhibit a high ratio of nucellar embryony (see Frost, this work, Vol. I, pp. 794 and 796). It is thus very uncertain what percentage of the seedlings would come sufficiently uniform in type to justify their use as rootstocks; this probably would depend on the variety and its origin. However, Terra (1932, p. 32) has stated that with "insufficient" selection the seedlings of the Pandan Wangi pummelo are sufficiently uniform for use as stocks; and the writer is informed[1] that seedlings of a Javanese pink shaddock variety (C.E.S. No. 2246) grown at the California Citrus Experiment Station, Riverside, were especially uniform and vigorous as seedbed and nursery trees.

According to Pope (1934, p. 4), the shaddock has proved one of the best citrus stocks for use in Hawaii, "because of its great vigor, adaptability to grafting, and apparent disease-resistant qualities." Thos. W. Brown (1924, p. 18), in discussing the use of the shaddock in Egypt, stated that it is supposed to be unrivaled as a stock on dry lands, but that it is so markedly subject to attacks of the scale insect *Aspidiotus aurantii* (probably either

[1] Information from Dr. L. D. Batchelor, Director, California Citrus Experiment Station.

*Aonidiella aurantii* or *Chrysomphalus aonidum*) as to make the raising of young stock difficult. He also mentions that the young seedlings are very variable, so that it is difficult to obtain uniform stocks.

Davis (1924, p. 58) mentioned the use of a "Pompelmoes" (pummelo or shaddock) as a rootstock in South Africa, and stated: "In the Graaff-Reinet District there are fine trees to be seen worked on this variety of citrus. It appears to the writer that it is calculated to make a good stock for the grapefruit." Webber (1925) found that, although the shaddock had apparently proved unsatisfactory in South Africa for sweet orange and mandarin varieties, some growers thought it to be promising as a stock for the grapefruit.

Three scion varieties of pummelo on Pandan Wangi pummelo rootstocks were found by Terra (1932), in Java, to be much slower in growth than on Rough lemon stocks, and somewhat slower than on sour orange or Japanese citron (*Citrus reticulata*, hybrid?). The Pandan Wangi, a superior fruit variety, produced, when budded onto rootstocks of its own seedlings, the smallest, poorest growth of any of the four stocks tested.

In studies made by Lee (1921) in the Philippine Islands with pummelo, sour orange, Calamondin, mandarin, and cabuyao (Kabuyao) stocks budded to lemon, lime, grapefruit, sweet orange, mandarin orange, and others, it was found that varieties on pummelo stocks exhibited a very high proportion of mottle-leaf disease and were much dwarfed in size, while those on mandarin and Calamondin orange stocks showed little or no mottling and were much larger, fine trees.

No pummelo variety is anywhere used extensively as a rootstock and, so far as is recorded, no thorough tests with it have ever been made.

## THE LEMONS

*Citrus Limon* (Linn.) Burmann

*The Rough lemon.*—For good performance in the nursery the Rough lemon is perhaps the most nearly ideal of any of the rootstocks commonly grown. It propagates easily from cuttings, and it produces numerous small seeds, which, if not dried out too much, germinate readily. The seedlings produced are from 90 to 100 per cent of nucellar embryonic origin and are thus very uniform and true to type, so that only about 5 per cent of the population of small seedlings require to be destroyed to eliminate the variants. In a given period of time, seedlings of Rough lemon grow more rapidly and make larger plants than those of any other citrus stock used in the United States. The seedlings are upright-growing, sparingly branched, and mainly with single trunks which require little pruning to place the buds. They take the buds readily and are easy to handle in the nursery.

The Rough lemon is more susceptible to injury from cold than sour or sweet orange, or grapefruit, but it sprouts quickly from the base of the trunk when frozen back. It is susceptible to gummosis diseases in about the same degree as, or slightly less than, sweet orange and grapefruit.

The Rough lemon develops a very wide-spreading, abundant system of lateral roots and commonly exhibits no marked taproot. Hume (1926, p. 203)

states that it develops a strong taproot, but W. Robertson Brown (1920), in illustrations from India, shows no taproot, and trees examined by the writer in California and Africa show only a weak development of the taproot in old trees (see fig. 56, p. 112). The Rough lemon will grow fairly well on all soils, but as a rootstock it is particularly adapted for use on light sandy or sandy loam soils, and on shallow soils underlain with rock near the surface. On such soils it is apparently more drought-resistant than the sour orange (Evans, 1922).

Davis (1924) has stated that in South Africa the Rough lemon is equally satisfactory on heavy loam soils, and the writer observed many good groves in that country on soils ranging from very light to very heavy, all on Rough lemon stocks.

The trees developed on Rough lemon stocks grow vigorously and are to be classed as standard in size, like trees on the sweet orange. The bud unions of Rough lemon with varieties of the sweet orange, lemon, grapefruit, and tangerine are usually nearly normal, and thus indicate good congeniality. (See p. 69, above.)

Fruit developed on Rough lemon stocks tends to be thick-skinned, rather large and coarse, and slightly inferior in quality, being somewhat lower in both sugar and acid than fruit on sour and sweet stocks. These differences, however, are not always very noticeable. Harding, Winston, and Fisher (1940), Harding (1940), Fudge and Fehmerling (1940), Camp (1941), and Sinclair and Bartholomew (1944) have all emphasized this inferiority of fruit grown on Rough lemon stocks, in comparison with fruit of the same varieties produced on sour and sweet orange stocks. Nevertheless, it must be recognized that on arid, light sandy soils, and under certain other conditions, the Rough lemon is the only stock that has given satisfactory crops—notably on the high, rolling hill section of central peninsular Florida. In summarizing the situation, Camp (1941, p. 78) stated: "It has been definitely shown that it is possible to produce excellent fruit on rough lemon rootstock even on light sandy soils by the proper use of magnesium, manganese, copper, and zinc in addition to the ordinary fertilizer constituents."

The experience gained in the use of Rough lemon stock in Florida has shown, in particular, that the reactions and success of a stock may, to an appreciable degree, depend on the fertilizer practices employed. According to Camp (1945), the Rough lemon, which is now the most widely used stock in Florida, was about to be discarded because of the poor quality of the fruit produced with it and the tendency of the trees to bear in alternate years and to suffer a heavy loss of leaves in the heavy crop years; but (Camp, 1945, p. 25): "With the development of the use of the so-called minor elements, it was found that much of the trouble with rough lemon stock was due to mineral deficiencies, and when these were corrected, difficulties in maintaining the trees in good condition disappeared and the quality of fruit showed very great improvement. . . . At present rough lemon stock is recommended for all light sandy soils and for all varieties of fruit grown on such soils with the exception of tangerines, tangelos, and other similar specialty fruits. . . . It is not recom-

mended for any wet soils because it will not stand waterlogging of the soil for any appreciable length of time; and because of its susceptibility to foot rot."

Fruits of sweet orange and tangerine varieties on Rough lemon, if held too late, tend to dry out and to exhibit much granulation. Bartholomew, Sinclair, and Turrell (1941, p. 26), in their study of the influence of rootstocks on granulation, noted that the amount of it exhibited by the same rootstock varied in different locations and in different seasons, and concluded that "climatic conditions and other factors may be more important than rootstocks in governing the production of granulation." It is, however, clear from their observations and from the experiences of growers that the proportion of granulation in such varieties as the Valencia on Rough lemon stocks tends to be high. With a late-ripening variety such as the Valencia, which frequently must be held until very late in the picking season, this characteristic of the stock may constitute a serious weakness.

Attention should also be directed to the observation of growers that grapefruit varieties grown on Rough lemon stocks tend to show a larger percentage of seed germination in the fruits held until late in the season than do grapefruits grown on sweet or sour orange stocks.

The Rough lemon is the principal rootstock used in South Africa, owing to the failure of the sour orange as a rootstock in that country and to the prevalence of collar rot (gummosis) on sweet orange stocks in many sections. The almost absolute dominance of the Rough lemon as a rootstock in South Africa is apparently ascribable to its resistance to the tristeza disease, and it is likely to become an important stock in other countries where that malady is present (see p. 101). The Rough lemon has given good results with varieties of the sweet orange and grapefruit in South Africa, but with varieties of the mandarin orange (*naartjes*), according to Marloth (1938), it is generally unsatisfactory, as the trees are short-lived. It has been used rather extensively in Australia, but in that country is yielding in popularity to the sour orange and, in some places at least, to the trifoliate orange.

Provan (1933) has cited the Maltese blood orange on Rough lemon stock as an interesting example of incompatibility occurring in Australia. Most varieties of sweet orange grow well on Rough lemon stocks, but this blood orange produces a small, stunted tree though the Rough lemon root system seems to be vigorous and healthy and constantly produces vigorous shoots just below the bud. Similar trees of this combination on two very different types of soil, representing almost the extreme differences in Victorian citriculture, were studied, and the combination reacted the same on both soil types. In the Mildure irrigation district of Australia, Provan and Cole (1944) reported the size, yield, and health of Washington Navel and Valencia orange trees on Rough lemon stocks to be inferior to those on sweet orange but superior to those on sour. (See p. 111.)

Schultz (1939) has stated that for use in the Tucumán section of Argentina the Rough lemon has no advantage as a rootstock over the sour orange, and its use cannot be recommended there.

Thos. W. Brown (1924, p. 17) reported rather favorably on the use of Rough lemon stocks in Egypt, but El Sawy (1936), twelve years later, stated that it had not been used to any great extent. "Its chief advantage," he wrote, "is the rapidity with which it forms a tree, and it appears to have a particularly desirable influence on the vigour and yield of Navel orange." In Hawaii it was discarded as unsatisfactory as a stock because of its susceptibility to gummosis (Pope, 1934).

Terra (1932) found that, with three scion varieties of the pummelo tested in Java on four rootstocks, the Rough lemon stock produced the largest growth, the sour orange the next largest, followed by the Japanese citron (*Citrus reticulata*, hybrid?), and the Pandan Wangi pummelo stocks in diminishing sequence.

From the evidence available it seems apparent that the Rough lemon should be used as a commercial rootstock only in those types of soil and in those countries where the sour orange and sweet orange rootstocks have been shown to be poorly adapted or entirely unsatisfactory.

*The Cuban lemon.*—This variety, known also as Cuban shaddock (see Vol. I, p. 604), probably of hybrid origin, has been found by Thomas R. Towns, of Holguin, Cuba, to be a good rootstock for Washington Navel oranges in that location. It produces numerous seeds, and reproduces very true to type. It is a vigorous-growing stock in the nursery, but produces a rather dwarfed, precocious, and productive orchard tree. It is being tested in California, but the trees are not yet old enough to permit reliable conclusions to be drawn.

*Other lemon varieties.*—Several lemon varieties, such as the Messer and the Hardison, have been tested as rootstocks in the Riverside experiments; but the seedlings were so variable, even after severe selections, that none of them could be classed as satisfactory stocks. All the standard lemon varieties grown for their fruits exhibit only low percentages of nucellar seedlings: Eureka, 34 per cent; Italian, 45 per cent; Lisbon, 20 per cent; Villafranca, 54 per cent (see Frost, this work, Vol. I, p. 794). As the embryos are thus largely of gametic origin, they may be expected commonly to be very variable. They are also susceptible to gummosis diseases, shell bark, and cold injury. The sweet lemon, Millsweet (see Vol. I, p. 608), as grown in the rootstock tests of the California Citrus Experiment Station, has shown no indication of being a good rootstock for lemon or orange varieties (see chap. iii, below). The lemon varieties that have given promising results as rootstocks, such as the Rough lemon and the Cuban lemon, are probably hybrids and give a high proportion of nucellar embryos. The so-called Palestine Sweet lemon, which is used extensively in the propagation of the Shamouti orange in Palestine, is now considered to be a sweet lime (see Vol. I, p. 628, and below, p. 122).

## THE LIMES

*Citrus aurantifolia* (Christm.) Swingle

*The acid limes.*—The acid limes have been little used as rootstocks, and their suitability and reactions with different citrus varieties are little known. Thos. W. Brown (1924, p. 75) has stated that "the [Egyptian] lime tree

[probably the same as the Mexican] is more resistant to drought than any other citrus trees" and that it may prove to be a valuable stock on dry, sandy lands. The Imperial Bureau of Fruit Production (1932, p. 32) has reported, from a circular issued by the Horticultural Section of the Egyptian Ministry of Agriculture, that "the Egyptian lime was found to have a more favourable influence on the yield of certain sweet oranges (such as blood and Valeucia) and mandarins (Clementine and Santara) than did three other stocks tried, namely sour orange, sweet lime and citron." Trees budded on it were also reported to show more vigor than those on the sour orange. Brown (1924, p. 17) states that the Egyptian lime tree "is almost immune to the attacks of 'mal-di-gomma,' " and Klotz and Fawcett (1930) also report limes to be rather resistant, being similar in this respect to the Rough lemon.

Of the use of this stock in Egypt, El Sawy (1936) has stated that it is well adapted to poor sandy soils, but not to wet heavy soils, and that scions grow vigorously on it and bear large crops of excellent-quality fruit.

In the United States the common acid lime, known under the varietal name "Mexican," has never been used as a stock, chiefly because of the small size of the tree and its susceptibility to cold injury.

*The Rangpur lime.*—The Rangpur lime, which is not a true lime but probably a sour mandarin orange (see Vol. I, pp. 619, 626), has, in the rootstock tests of Schultz (1939) in Tucumán, Argentina, given promise of being a valuable rootstock for varieties of the sweet orange, mandarin orange, and grapefruit. According to Schultz, it tends to stimulate fruiting at an early age and gives good yields of good-quality fruit. It is suitable for midseason and early-ripening varieties of the sweet orange, but not for late-ripening varieties, as it tends to hasten the period of ripening. In Tucumán it was found to hold its fruits better than other rootstocks through periods of hot winds and excessive temperatures.

According to Bitancourt,[1] of the Instituto Biológico, São Paulo, Brazil, the Rangpur was commonly used as a rootstock in Brazil some fifteen years ago, primarily because of its rapidity of growth and the quickness with which standard-sized nursery trees could be produced. As it turned out, however, the orchard trees grew well for a few years and then gradually slowed down in growth and began to decline. Hence in Brazil the Rangpur is no longer considered a satisfactory stock.

In recent investigations on the tristeza disease in Brazil and Argentina (Bitancourt, 1940–1941; and above, p. 100) it has been found that the Rangpur lime is noticeably resistant to the injury, and this good character may be found to outweigh its objectionable ones.

In Java the so-called "Japansche Citroen," which seems to be similar to the Rangpur lime (see footnote 1, p. 101), was found by Toxopeus (1937) to be very resistant to a disease similar to, or perhaps the same as, tristeza. As to the use of the "Japansche Citroen" as a rootstock in Java, Ochse (1931, p. 121) wrote: "This stock produces seedlings, which for a great part originated vegetatively [nucellar seedlings] and hence do not differ from the

[1] Personal statement to the writer in 1941.

mother-tree. It has proved eminently fit for stocks for diverse forms of *Citrus Aurantium, Citrus maxima* and *Citrus nobilis* [sour orange, pummelo, and mandarin orange]."

In the United States the Rangpur has nowhere been thoroughly tested as a rootstock. In Florida the writer has observed a few trees that were said to be on this stock, but they were small and not outstanding. Until it has been more thoroughly tested, it should be used only in small trial plantings.

*The sweet limes.*—The sweet lime most commonly employed as a rootstock is the Palestine (see Vol. I, p. 628), which is the dominant stock used in propagating the Shamouti orange in Palestine (Yedidyah, 1931; Oppenheim and Rapoport, 1932). According to Yedidyah (1933), this lime is sensitive to foot rot and frost, and its life is generally short. In his experiments, trees on this stock came into bearing earlier and fruited more heavily than those on sour orange, the other stock most commonly used in Palestine. The Palestine lime when used as a stock for the Shamouti orange is also very susceptible to the disease xyloporosis (Reichert and Perlberger, 1934). It is a strong, vigorous grower, similar to the Rough lemon; it produces a high proportion of nucellar embryos, and thus comes nearly true to seed; and it handles easily in the nursery. As the Shamouti orange grown on this lime is famous for its quality, it must be considered a successful stock for that variety.

Hodgson (1931), after a study of conditions in Palestine, concluded that the sweet lime was an unsatisfactory stock and that some slower-growing stock, perhaps even the sour orange, would prove longer-lived and, in the long run, more satisfactory. On the contrary, Lewin (1930), a Palestine grower, considers that the sweet lime has an advantage over sour orange in almost every character, its sole disadvantage being its liability to gummosis, which he thinks can be controlled. Weston (1932*a*, 1932*b*) described two adjoining and comparable plantings of the Jaffa (Shamouti?) orange on the shore of the Sea of Galilee, one on sweet lime stock seventeen years old, and the other on sour orange fifteen years old. The trees on sweet lime were showing "dieback," and many were infected with gummosis; they were not uniform and had only a fair crop of inferior fruit. The trees on sour or bitter orange, although two years younger than those on sweet lime, were much larger, markedly uniform, free from disease, and carrying a heavy crop of the highest-quality fruit.

The Palestine sweet lime is said by all writers to be well adapted only to light soils, and this may be one reason for the conflicting opinions on its comparative value.

According to El Sawy (1936), the sweet lime (Palestine?), in Egypt, is suited to light soils but not to heavy soils, and suffers more than any other stock from high water tables. The trees formed are usually dwarfed and short-lived, except those budded to the Satsuma orange and seedless lime. The fruits of trees on this stock are large and relatively thick-skinned.

Nowhere in the United States has the sweet lime been used as a stock in commercial orchards, but it is under trial with varieties of orange, lemon, and grapefruit in the experiments of the California Citrus Experiment Station.

## THE CITRONS

(*Citrus Medica* Linnaeus)

The citron, apparently because of its vigorous early growth, readiness of sprouting from cuttings, and ease of budding, was used as a rootstock in the early development of the citrus industry in many countries. More than fifty years ago, the writer talked with several Florida growers who still thought the citron a promising rootstock. A citron variety, possibly a hybrid, known as the China lemon (see Vol. I, p. 638), was used in California in the early stages of the industry (1880 to 1890), but was soon discarded. A few scattered old trees of such plantings were still living in 1925 and were examined and photographed by the writer. Washington Navel on this stock exhibited a very large swelling or overgrowth of the scion at the bud union, and the tops were dwarfed, though not severely. The scion trunks of such old trees, 1 to 1½ feet above the overgrowth, were smaller than the stock trunks. (See, in discussion of interrelations between stock and scion, p. 79 above, and fig. 38, p. 73.) In the United States, no commercial use has been made of any citron stock since about 1890, or earlier.

The citron has been extensively used in India, where W. Robertson Brown (1920) demonstrated that with the Malta orange it produced severe dwarfing and should not be used. With the mandarin (Santara), it gave a fairly satisfactory growth during a seven-year experiment, but the branches began to die in the sixth year (see fig. 43, p. 81). Singh and Singh (1942) emphasized the good nursery qualities of the citron, but stated that its reaction with sweet orange (Malta) and grapefruit indicated incompatibility, the scion invariably outgrowing the rootstocks. With the mandarin, however, the union was normal and the growth fairly vigorous.

Thos. W. Brown (1924) stated that a local citron stock is the one most widely used in Egypt for the propagation of orange and mandarin trees. The citron stocks are grown from cuttings planted in February; they are budded the following September and are fine young trees at the end of the second year. Trees on this stock grow quickly, yield more freely when young, and produce somewhat larger fruit than those grown on the bitter (sour) orange. They are, however, said to be short-lived, more subject to disease, and very much inferior to those grown on the bitter orange. El Sawy (1936) also considered the citron a poor stock in Egypt, as it produces dwarfed trees which are usually unhealthy and short-lived. The fruit on this stock, he stated, is coarse and of poor quality.

## THE TRIFOLIATE ORANGE

*Poncirus trifoliata* (Linn.) Rafinesque

The trifoliate orange produces numerous plump seeds which germinate easily, but the seedlings grow rather slowly. It produces upright-growing, sparsely branched seedlings, which are very thorny. It buds easily and is easy to handle in the nursery, but owing to the slow growth of seedlings and buds it is likely to require a year longer than other varieties in the nursery to pro-

duce standard-sized budlings. It reproduces fairly true to type (70 per cent or more nucellar-embryonic; see Webber, 1900*a*) and requires the removal of but few of the seedlings to eliminate variants, the seedlings being commonly more uniform than the percentage of nucellar embryony would indicate.

The trifoliate orange is the most cold-resistant of the stocks commonly used, but it sometimes sprouts poorly from the stock trunk when scion tops are frozen. Occasionally it renders the scion slightly more hardy, an effect supposed to be caused by the greater tendency to dormancy which the trifoliate induces (see above, p. 95). It is a deciduous tree and has a more marked dormant period in winter than the evergreen species of citrus used as stocks. On the other hand, the writer has observed nursery trees on trifoliate that were more seriously injured than similar seedlings on sour orange, the stocks themselves being killed back into the soil (Webber, 1925). It is noteworthy that, in general, the trifoliate has given its most satisfactory results as a stock in the most northern and coldest citrus sections, and has not responded so satisfactorily in warmer sections more tropical in location (Hume, 1926, p. 208).

Of the trifoliate orange, Fawcett (1936, p. 20) has stated: "It is resistant to mal di gomma, brown-rot gummosis, and other gum diseases. It is very susceptible to Citrus canker and moderately susceptible to scab." Although it is commonly considered to be more resistant to gummosis disease than any stock other than the sour orange, this conclusion is open to doubt. Klotz and Fawcett (1930, p. 422), as a result of inoculation experiments, stated: "Specimens of trifoliate orange . . . proved more susceptible than lemon to the artificial inoculations, and in the laboratory less inhibitive than lemon." It seems probable, however, from field experience, that this stock is the most resistant to gummosis infections of any of the stocks now used commercially, other than sour orange.

Of trifoliate stock in Japan, Tanaka and Tanaka (1932, p. 2) stated: "Although it is rather susceptible to Citrus canker, foot-rot, and gummosis, it is valued very highly for its extraordinary hardiness."

The trifoliate orange develops a well-branched root system with very abundant fibrous roots, but the roots do not spread so widely as those of the Rough lemon or the sweet orange. It is said to be adapted for use on fairly rich, low, moist soils and is generally regarded as unadapted for use on light, dry, sandy soils or on calcareous soils. It is said to give the best results on soils that are slightly acid and contain an abundance of organic matter. In the rootstock trials of the California Citrus Experiment Station, with Valencia orange scions, trifoliate orange has given better results at Riverside on a sandy loam soil than at Tustin on a fairly heavy loam soil, both of which are alkaline in reaction. The information now available does not permit a trustworthy conclusion concerning its soil adaptability.

This stock usually has a marked dwarfing effect on the scions of lemon and grapefruit, but with some varieties of sweet orange and mandarin it produces trees only slightly smaller than those on sweet or sour orange. The bud unions usually exhibit a marked overgrowth of the stock (see figs. 38 and 42, above),

but this does not seem greatly to influence the development and longevity of the tree (fig. 58).

The fruit produced on trifoliate stocks tends to be rather small, but it is usually of high grade and excellent quality. It tends to increase granulation with some varieties, such as the Valencia (Bartholomew, Sinclair, and Turrell, 1941).

*A* *B* *C*

Fig. 58. Comparative size of Satsuma orange scions, and nature of bud union, on various stocks: *A*, Calamondin orange (note overgrowth of scion); *B*, Koethen sweet orange; *C*, trifoliate orange (note overgrowth of stock). Trees ten years old.

In general, the trifoliate orange stock is adapted to a very narrow range of conditions and varieties, and has proved successful in only a few locations, with special varieties. It is used extensively as a stock for the Satsuma in Japan (Tanaka and Tanaka, 1932) and in the southeastern United States. It is commonly used for the kumquat, which on this stock is very hardy, the cold-resistance of the stock being coupled with the extreme winter dormancy of the scion. It is also commonly used for the kumquat, and for the Bouquet sour orange and some other varieties, when these are grown as pot plants or ornamentals.

The trifoliate is an erratic stock, and its reaction cannot always be predicted. Its dwarfing influence has been noted by almost all students of rootstocks, yet it sometimes produces standard-sized trees. In certain tests at the California Citrus Experiment Station, Valencias on this stock, at twenty-

two years of age, were as large as those on sweet or sour orange stocks; but the writer has studied plantings of Valencias on trifoliate in at least two other places in California where the trees were markedly dwarfed. It seems probable that this difference is due to the use of genetically different strains of the trifoliate, or perhaps in some degree to differences in soils. Two rather markedly different strains are well known to exist in cultivation in the United States, and doubtless there are others not now recognized.

Several times, the writer examined a series of experiments conducted by G. L. Taber, at Glen St. Mary, Florida, in which trifoliate orange, sour orange, and sweet orange rootstocks were tested over a period of several years, with a number of scion varieties of sweet orange, mandarin orange, and grapefruit.[1] The trees on trifoliate stocks were generally somewhat dwarfed, but those of the Du Roi, Jaffa, Pineapple, and Homosassa oranges, the King tangerine, and the Duncan grapefruit, on trifoliate stock, were about the same size as comparable trees on sour orange stocks. It was found that all the varieties came into bearing at an early age when budded on trifoliate orange, and that they were consistently heavy bearers. A general tendency of the fruit on trifoliate stocks to ripen earlier than that on sweet or sour stocks was also observed. The fruit on trifoliate was of notably good quality and was less coarse than that on sour orange stocks.

Bonns and Mertz (1916, p. 301), in summarizing the results of an early experiment at the California Citrus Experiment Station, stated: "It must be pointed out in conclusion that this Station, despite the favorable results so far obtained with the trifoliate orange as a stock for oranges, cannot recommend it at present, in view of the fact that well-defined cases are known where its use has been injurious."

On the use of the trifoliate orange, Tanaka and Tanaka (1932, p. 2) stated: "From a horticultural standpoint, the trifoliate orange is the most ideal rootstock of loose skin oranges in the temperature region where no killing by frost takes place." Davis (1924), in South Africa, found that the effect of the use of this stock was to dwarf every kind of lemon and grapefruit and practically all sweet oranges, with the exception of late varieties like Du Roi and Valencia. These, and most kinds of *naartjes* (tangerines), were very little dwarfed. Thos. W. Brown (1924, p. 18) stated: ". . . trials in Egypt have demonstrated the fact that it is entirely unsuited to the conditions of this country." In the citrus section around Tucumán, Argentina, according to Schultz (1939), the trifoliate orange is not so good as the sour orange and should not be used for grapefruit or lemon varieties; nor should it be used for late-ripening orange varieties, as it accelerates the ripening of the fruit. In an experimental planting of Marsh grapefruit (trees about seven years old) in New South Wales, Australia, Benton (1937) found that those propagated on trifoliate orange stocks produced trees of a size intermediate between those on Rough lemon stocks, the largest, and those on sour orange, the smallest. The fruit produced by the trees on trifoliate stock was judged to be the best in flavor, and that on Rough lemon the poorest.

[1] Mr. Taber's discussion of these experiments was quoted by Hume (1913, pp. 207–216).

It seems evident from a recent statement of Benton's[1] that the trifoliate is growing in favor as a rootstock in Australia. He wrote: "Practically all our trees are on Rough lemon—a few are on sweet orange. We intend replacement with Valencias on Trifoliata where possible as that stock grows much more satisfactorily than sour and in trials has proved quite immune to Phytophthora attack."

Not long ago, the Irrigation Research Extension Committee (1943, p. 13) of the Murrumbidgee irrigation areas in Australia stated: "Recent work indicates that much old citrus land is liable to be heavily infested with the fungus phytophthora and that Trifoliata stock is the only one resistant to this. At present this stock can be recommended only for Valencias, mandarins and grapefruit." The experience with this stock in California is much different, and it could not be recommended without reservations, especially for Marsh grapefruit. (See chap. iii, pp. 208–209.)

In the writer's opinion, the trifoliate orange, as judged by experience and the results of experiments, cannot be considered a satisfactory general-purpose stock for varieties of the sweet orange, mandarin orange, lemon, or grapefruit. It does have value as a special stock for Satsuma varieties, kumquats, Valencia orange in some sections, and possibly certain other sorts.

### THE CITRANGES (TRIFOLIATE ORANGE × SWEET ORANGE)

Some of the citranges have proved hardy, vigorous growers, developing into large, standard-sized trees as seedlings, and certain varieties seem likely to prove valuable for use as stocks. Some varieties mature but few seeds, while others, such as the Savage and Troyer, in California, commonly produce seeds in sufficient numbers for general nursery purposes. Mortensen and Riecker (1942) made careful records of the number of seeds produced by different citrange varieties at Winter Haven, Texas, in 1939, 1940, and 1941. Counts for ten fruits of each variety each year for the three-year period gave the following average number of seeds per fruit: Carrizo, 20.2; Cunningham, 2.1; Morton, 1.6; Rusk, 3.4; Rustic, 3.5; Savage, 9.0.

Seed development in most citrange varieties is almost wholly by nucellar embryony; hence they reproduce very true to type. The difference in size among young seedlings is due mainly to differences in the size of the nucellar embryos. The seeds germinate readily and develop strong single trunks, little branched, so that they are easy to handle in the nursery. They are more cold-resistant than any stock used, other than the trifoliate, and appear in general to be stocks more congenial than the trifoliate for the various species of *Citrus*. Their degree of disease resistance is not well known. In the experimental inoculations with Pythiacystis gummosis of Klotz and Fawcett (1930, p. 420) and Fawcett (1936, p. 177) the Sanford and Cunningham were found to be very resistant to the disease, whereas the Coleman was extremely susceptible. The Savage, Rusk, and Morton were intermediate in susceptibility between the two extremes.

[1] R. J. Benton, Citrus Specialist, Department of Agriculture, Sydney, Australia; letter of November 30, 1942, to M. B. Rounds, Riverside, California.

It is of interest to note that, of the citranges tested as rootstocks in experiments at the California Citrus Experiment Station, the growth reactions as indicated by size and vigor of trees with scions of sweet orange, mandarin orange, and grapefruit seem to be correlated with the nearness of the similarity of the citrange hybrid to one or the other of its parents. Those varieties, such as the Cunningham and Rusk, that are most nearly like the trifoliate parent in having small, regularly trifoliolate leaves, and that are nearly deciduous in habit, even though they are quite different from pure trifoliate orange, react similarly to it when used as rootstocks. On the other hand, such citranges as the Savage, and particularly the Morton, which more nearly resemble the sweet orange parent in having much larger leaves less regularly trifoliolate, and which are more nearly evergreen in habit, when used as rootstocks, react on scions more nearly like the sweet orange parent. This seems to indicate that it is possible, here, to choose the most promising rootstock types among citranges on the basis of their resemblance to the parental species.

The following are notes on different varieties.

*Rusk.*—The Rusk (sweet orange ♀ × trifoliate orange ♂) has been tested on a fairly extensive scale in Alabama and Florida as a stock for the Satsuma and has been recommended for general use with that variety. In the California Citrus Experiment Station trials with Satsuma, Rusk citrange produced healthy, fine trees, slightly dwarfed, and not outstanding in yields. There was no appreciable difference between budded seedlings and cuttings, both of which were tested during a period of eight fruiting years. The trees on Rusk were much smaller than those on Morton citrange (fig. 59) and were much lower in yield.

*Morton.*—Of all the citranges that have been tested, the Morton (trifoliate orange ♀ × sweet orange ♂) seems to have given the most promising results as a rootstock. Apparently, it is especially good with the Washington Navel and the Satsuma (fig. 59). Sweet orange and mandarin orange varieties grow well on the Morton citrange, producing tops that are but slightly smaller than those on sweet orange stocks. The trees in the experimental trials, during periods of ten to seventeen years, have remained vigorous and healthy and are uniformly heavy yielders every year.

In the tests at the California Citrus Experiment Station, Washington Navel orange on Morton citrange stock gave an average annual yield of 220 pounds for each of 5 experimental trees, during the first ten fruiting years. This was an average yearly increase of 68 per cent over the yield of Washington Navel on sweet orange stock (av., 131 lbs. per tree), which gave the next highest yield (see table 12, p. 188). With the Owari Satsuma, 5 trees on Morton stock, during the first eight fruiting years, gave an average annual yield of 91 pounds per tree, in comparison with a similar average for sweet stock of 76 pounds per tree, or an increase of 20 per cent for the Morton. In the experiments of another year, 16 trees of Owari Satsuma on Morton stock, during the first seven years of fruiting, gave an average annual yield of 79 pounds per tree, in comparison with an average of 57 pounds per tree for sweet stock, an increase of approximately 38 per cent in favor of the Morton. It is true

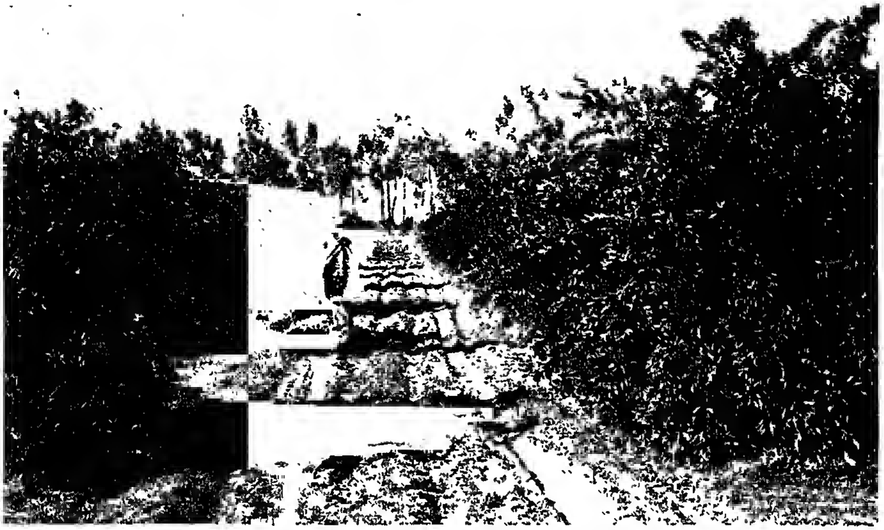


Fig. 59. Owari Satsuma on Rusk citrange stock (*left*) and on Morton citrange stock (*right*). Trees ten years old. Note the greater vigor of trees on Morton citrange.

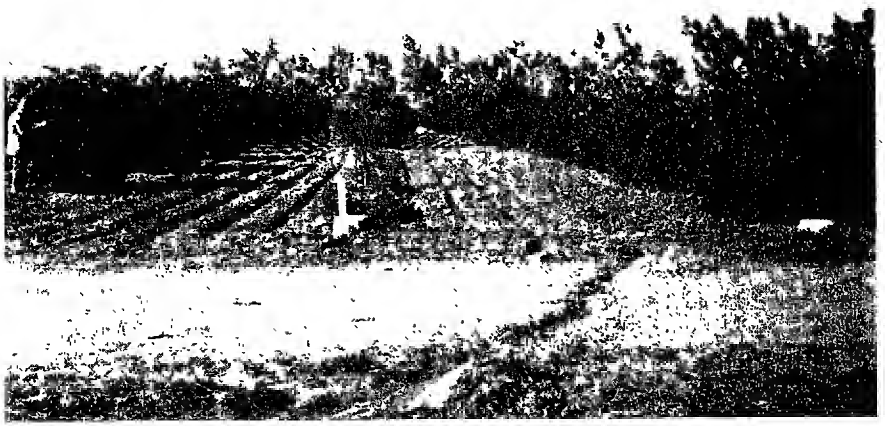


Fig. 60. Satsuma orange scions on citrange rootstocks: *left,* five trees on Savage citrange; *center,* five trees on Coleman citrange (all dead); *right,* five trees on Cunningham citrange. All trees ten years old and considerably dwarfed. (Compare with figure 59.)

that these are results from a limited number of trees over comparatively short periods, but they represent comparisons with sweet orange stock, which, next to the Morton citrange, proved to be the most consistent high-yielding stock for these varieties, of the more than twenty-five different rootstock varieties tested. (See chap. iii, p. 197.)

Unfortunately the Morton develops few seeds, and this is a great handicap to its general use as a stock. Dr. W. T. Swingle has stated (in conversation) that, in a few carefully guarded pollination tests made in Florida, Morton fruits pollinated with grapefruit pollen had been found to set seeds freely. In California this method has been tested in a limited way by Batchelor and Rounds, but thus far the experiments have been unsuccessful (see p. 191). In a limited trial made by the writer, scions of the Morton were found to root readily in peat moss, when kept in a moist chamber. It would seem entirely feasible to use cuttings to propagate budding stock if seeds cannot be produced in quantity.

*Savage.*—The Savage citrange (trifoliate orange ♀ × sweet orange ♂) also merits careful trial as a rootstock. It makes a large, vigorous-growing tree and is healthful and fruitful. It develops more plump, good seeds than most citranges, usually giving 3 to 4 per fruit, and in some seasons 15 to 20 per fruit. It is nearly 100 per cent nucellar-embryonic, and for this reason the seedlings produced are markedly uniform in type.

Next to the Morton, the Savage seems to be the most promising of the citranges thus far tested as rootstocks, though its reaction is favorable with but few varieties. In the Riverside experiments it has given good results with Satsuma (fig. 60), the trees of which grow larger on Savage citrange than on trifoliate orange or Rusk citrange. Marsh grapefruit on Savage citrange stocks are somewhat dwarfed but are intermediate in size between those on trifoliate and those on sweet orange. They remain healthy, vigorous, and productive, at least through the first few fruiting years; no observations over a longer period are available. Experiments with this stock in its reaction with Marsh grapefruit indicate to the writer that if the trees are planted closer together than those on ordinary stocks (say, 15 feet by 20 feet), gaining thereby approximately 60 per cent more trees per acre, the stock may prove valuable. The fruits produced are in general of excellent size, grade, and quality, and the trees remain small and easy to pick. (See also chap. iii, p. 204.)

*Other citranges.*—In the California experiments the citrange varieties Coleman and Cunningham have also been tested as rootstocks, but they have not given noteworthy results. Coleman is apparently incompatible with Satsuma. as more than 75 per cent of the trees withered and died within the first ten years after planting, and none of them were fully satisfactory (fig. 60). In all cultivations the Coleman has been short-lived when grown as seedlings, when budded on other rootstocks, or when used as the stock. These observations and its high susceptibility to gummosis, as shown by the inoculation experiments of Klotz and Fawcett (1930, p. 420), apparently indicate a fundamental weakness in this hybrid variety. Furthermore, it produces but very few seeds. The variety may therefore be discarded as a stock possibility.

The Cunningham produces a large, vigorous, healthy tree, more nearly resembling the trifoliate orange than the Savage, and apparently is not as promising for stock purposes as the latter. It is hardy and gummosis-resistant, however, and produces seeds in numbers sufficient to make its nursery use practicable. Although experiments with the Cunningham in California have not been favorable (see chap. iii, pp. 182, 185, 191, 197, 204), it may give more promising results elsewhere under different conditions (fig. 60).

Another citrange, the Troyer, because of its vigor and general good nursery characters, seems to merit careful trial as a rootstock. It has not yet been tested as a stock in California, but has been used experimentally for Satsumas in Alabama, where preliminary results have been favorable. The Troyer is a vigorous, large tree; it is also very fruitful and develops many large plump seeds. It should be thoroughly tested as a stock, especially for Satsuma, mandarin, sweet orange, and grapefruit varieties.

The Carrizo citrange (C.P.B. No. 45019 B), named in Florida by T. Ralph Robinson and H. P. Traub, has been found by Mortensen and Riecker (1942) to produce an abundance of seeds for nursery purposes, and limited tests indicated that it gave excellent results with Satsuma varieties. Its good nursery characteristics indicate that it should be tested more widely.

Interesting studies on the use of citranges and certain other hybrid citrus varieties as rootstocks, made at the Winter Haven substation of the Texas Agricultural Experiment Station, have been examined by the writer. Mortensen's[1] statement summarizing the results follows:

"Although exact valuations are not possible due to insufficient replications, the trend shows trifoliate, Morton, Rusk, Carrizo and TS 15137 citranges to be generally good stocks for satsumas. As might be expected, each combination of scion and stock is a different problem. For example, Kawano Wase has produced much better on citranges than on trifoliate, particularly on TS 15137, Rustic, Carrizo and on citrangequat. Owari also did better on the citranges than on trifoliate particularly Morton and Carrizo. Silverhill satsuma, on the other hand, did much better on Cunningham than other citranges but produced about as well on trifoliate as on Cunningham. In other words, the citranges seem to have improved tree growth and yields over the trifoliate for at least some varieties.

"With oranges, the citranges also appear to be better than trifoliate in most cases. We do not have Carrizo citrange in the earlier tests. Hamlin has yielded significantly higher on 15137 citrange than on Cunningham or trifoliate. Joppa yields are considerably higher on Rusk than on citrangequat or trifoliate. Texas Navel is about the same on Rusk, Morton, Cunningham and 15137 citranges and trifoliate. Grapefruit has not been tested extensively. Marsh Pink has done about equally well on sour orange and Sacaton citrumelo. Redblush grapefruit is dwarfed on Cunningham citrange but is performing well on Carrizo and Rusk. Marsh grapefruit is doing exceptionally well on Carrizo. Little River has produced considerably better on Cunningham than

[1] Superintendent E. Mortensen, Winter Haven, Texas; letter of July 6, 1945, to H. J. Webber.

on Carrizo. Meyer lemon is producing well on Carrizo citrange but we have no checks. Webber tangelo is doing very well on Carrizo citrange but there are no checks."

THE TANGELOS (GRAPEFRUIT × MANDARIN ORANGE)

*Sampson tangelo.*—In the organization of the rootstock experiments at the California Citrus Experiment Station, in 1922, the writer chose the Sampson tangelo as one of the varieties to test. This choice was based on the outstandingly vigorous growth made by about twenty seedlings at the Station and their exceptional uniformity. Later it was found by inoculation tests that this tangelo is rather highly resistant to attacks of gummosis (Klotz and Fawcett, 1930; Fawcett, 1936); but field observations indicate that its resistance may be modified under some conditions (see chap. iii, p. 209).

The Sampson tangelo produces a considerable number of medium-small seeds and makes a satisfactory nursery tree, although its growth is usually slow at first. It reproduces nearly true through the seed, as it is approximately 100 per cent nucellar-embryonic. Experience with it is as yet limited, but trees of sweet orange, Satsuma, grapefruit, and lemon varieties budded on this stock, so far as tested, grow vigorously into standard-sized trees but are sometimes low in yield (see chap. iii). It seems to be especially suited for use as a rootstock for lemon varieties, with which its performance in the California Citrus Experiment Station tests has been outstanding, especially on heavy soils. The results of these preliminary experiments with the Sampson justify its wide experimental trial. No other tangelo has yet been tested as a rootstock, so far as is known to the writer.

THE YUZU ORANGE

The yuzu orange, a hybrid (*Citrus ichangensis* × *C. reticulata* var. *austera* ? See Vol. I, p. 427), is used to a limited extent in Japan, particularly as a stock for the Satsuma. In the Satsuma section of the southeastern United States it is not considered equal to the trifoliate, but it has not been adequately tested. T. Tanaka (1929*b*, p. 141) has stated that the "Yuzu (*C. junos*) has been used for many hundred years as a good rootstock in Japan."

The Imperial Horticultural Station at Okitzu, Japan, reports noteworthy differences between yuzu and trifoliate oranges: the trifoliate contains 30 polyembryonic seeds per fruit; the yuzu, 20 monembryonic seeds. Trifoliate seedlings grow rapidly and can be worked in their second year, whereas with yuzu it is necessary to wait till the third year. The trifoliate produces a strong initial bud growth and is early-bearing, slowing down in the fourth year to develop into a dwarfish tree, while it is just at this age that the yuzu begins to grow rapidly. The fruits on yuzu are at first larger, with thicker, rougher skins, and more acid than those on trifoliate; but as the trees age they produce smooth, polished, tight-skinned fruits that, according to general belief, far surpass in quality those produced on trifoliate stocks. It has become a practice of Satsuma growers to graft (inarch) a root of the deep-rooted, long-lived yuzu onto Satsumas that already have a trifoliate root. (The fore-

going information is condensed from an Imperial Bureau of Fruit Production Technical Communication, 1932, p. 27.) In Japan, the fruits of the yuzu are used as we use lemons; this tends to render the seeds costly, whereas the fruits of the trifoliate orange have no other use than for their seeds.

It is interesting to note that Japanese investigators (Imperial Horticultural Experiment Station, Okitsu, Japan, Research Bulletin 4, 1925; Nagai and Takahashi, 1925, 1928) also obtained very suggestive results with yuzu in recovering decadent Thomson Navel orange trees on trifoliate rootstocks by inarching them with different stocks, namely, yuzu, sweet orange, sour orange, Japanese Summer orange (*C. Aurantium, intermedia* Tanaka), and trifoliate orange. All trees inarched with yuzu, sweet, sour, and Japanese Summer orange showed marked recovery after a period of eight years, but those with yuzu gave the best results, as judged by increase in growth, fruitfulness, and quality of fruit (see fuller discussion, p. 159, and fig. 69).

Fauvel (1940), in comparing the yuzu with the trifoliate orange as a rootstock in Algeria, stated that yuzu is slow-growing and can only be grafted when three years old, whereas trifoliate can be grafted when two years old.

## THE CALAMONDIN

The Calamondin (*Citrus reticulata* var. *austera* ? × *Fortunella* sp. ? See Vol. I, p. 357) has been used to some extent in Asiatic countries as a stock. It is very cold-resistant—probably equal to the Satsuma in this respect; and in Texas it is reported to have rendered the lime budded on it much more cold-resistant than normally. It is thought, in that state, to be a good stock for the kumquat, sweet orange, and mandarin. Seedling trees of the Calamondin do not grow well in California, but they make fine trees in Texas. Tanaka and Tanaka (1932) state that it is often employed as a rootstock for mandarin varieties in the vicinity of Swatow, China.

The Calamondin orange has been tested in the rootstock experiments at the California Citrus Experiment Station, budded with varieties of sweet orange, Satsuma, and lemon, but after seven to ten years of fruiting has not given satisfactory growth or yields in comparison with the stocks commonly used. As an illustration, the average annual yield of 16 trees of Owari Satsuma on Calamondin, for seven years, was only 39 pounds per tree, during which period the average for sweet orange was 57 pounds, and for Morton citrange 79 pounds per tree.

When this Satsuma experiment was discontinued, in 1939, and the trees were pulled, it was found that those on Calamondin stocks had developed very large taproots (one or two per tree) which extended straight down five or six feet or more, and had but few laterals near the surface (fig. 61). Of the twenty-five rootstocks under trial, the Calamondin exhibited the most marked taproot development, with *Citrus Webberii* (fig. 61) next, and the sour orange next, the other varieties showing very little indication of taproot development. With all varieties the same ordinary nursery method had been followed, the taproots having been shortened in transplanting from the seedbed to the nursery and again in transplanting from the nursery to the orchard.


Fig. 61. Taproot development in citrus rootstocks: *left*, Calamondin orange; *right*, *Citrus Webberii;* both rootstocks budded to Satsuma orange scions. Trees ten years old, propagated by the ordinary nursery methods, and grown in the rootstock experiments of the California Citrus Experiment Station, Riverside. (Compare with figure 56.)

### THE YAMA-MIKAN

The Yama-mikan, or mountain mandarin, which is classed by Swingle (this work, Vol. I, p. 409) as a sour orange hybrid, is used as a rootstock in Hyûga Province, Japan (Tanaka and Tanaka, 1932, p. 3), and is said to correspond to the sour orange in vigor and habit. It is semiwild in Japan (T. Tanaka, 1927).

### THE OTAHEITE ORANGE

The so-called Otaheite orange, which is classed by Swingle as a lemon × mandarin hybrid and by the writer as a lime × mandarin hybrid (see this work, Vol. I, pp. 401 and 630), has been used to some extent as a dwarfing stock for orange varieties and produces early-fruiting trees of small size. It is usually propagated by cuttings, as it is nearly seedless. It is very susceptible to frost injury and evidently has no value as a commercial stock.

### NEAR RELATIVES OF CITRUS

Many of the close relatives of *Citrus* have been suggested as possessing value for use as rootstocks, and at least one such relative, the trifoliate orange (*Poncirus trifoliata*), has been used extensively and more or less successfully in many countries (see discussion, p. 123). None of the others, so far as is known to the writer, have shown any real promise of value for use directly (unmodified) as budding stocks.

Dr. W. T. Swingle and his associates of the U. S. Department of Agriculture have conducted extensive studies and experiments on the use of various of these relatives of *Citrus* as rootstocks for citrus varieties, and many suggestions and results from trials will be found recorded under different species in his chapter on "The Botany of *Citrus* and Its Wild Relatives"—chapter iv in Volume I of this work. (For a summary of Swingle's suggestions see also Imperial Bureau of Fruit Production, Technical Communication, 1932, pp. 36–38.)

In the Riverside experiments only two of these citrus relatives, other than the trifoliate orange, have been tested, namely, *Eremocitrus glauca* and *Severinia buxifolia*. Seedlings of both of these species are slow in growth and must be held several years longer in the nursery than ordinary citrus rootstocks in order to reach comparable budding and transplanting size. Five buddings of Eureka lemon, five of Marsh grapefruit, and five of Washington Navel, on *Eremocitrus glauca,* were planted in 1931. These all remained severely dwarfed, and tree after tree gradually deteriorated, died, or was removed because of its hopelessly bad condition. Of the three combinations the Eureka lemon was the best, and one tree of the five was still alive in 1943. At twelve years of age it was approximately 7 feet high, with a top diameter of 8 to 9 feet, or about one-fourth standard size. The foliage is open, small, and mottled, and the tree has many dead branches. The fruits are small, coarse, and much ribbed. The bud union is smooth and even and apparently is nearly normal.

The trials of seedling *Severinia buxifolia* stocks budded with Washington Navel and Valencia oranges, Eureka lemon, and Marsh grapefruit, of which

there were four to five trees of each combination, were little better than those of *Eremocitrus*. All were still living at the close of the tenth year in the orchard, but all were severely dwarfed (about one-fourth standard size), and all the scions were severely swollen and overgrown at the bud unions. The scion trunks, a foot above the swollen portion at the union, were only slightly larger than the stock trunks. All the trees looked stunted and sickly, with small leaves and few to many dead branches.

Of these combinations the Marsh grapefruit seems to be the most satisfactory. The five trees of Marsh grapefruit, in 1942, were well loaded with smooth, good-sized fruit, but the yield per tree was small because the trees are small. If these trees were planted as much closer together than standard-sized trees as their comparative size would indicate to be possible, the yields might be satisfactory. Tests of such plantings, were they to be made, should yield interesting results.

It should be noted that when these trees were between five and six years old from date of planting in the orchard and were found to be severely dwarfed, sprouts springing from the *Severinia* stock trunk were permitted to remain and grow, in the hope that they might assist in better nourishing the stock. Such sprouts after five or six years' growth are usually large and extend through and to the top of the scion tree. These trees were nearly as large at five to six years of age as they were five years later. No trees with stock sprouts removed were left for comparison, but it seems certain that the stock sprouts left growing have exercised no visible beneficial influence on the growth of the scions.

In all the above-mentioned tests of *Eremocitrus* and *Severinia* as rootstocks, the budlings were produced by the nursery methods commonly used. Dr. Swingle, however, in discussions with the writer, has emphasized that the use of such citrus relatives as *Eremocitrus, Severinia, Swinglea,* and the like as rootstocks probably will necessitate the employment of special techniques in producing the nursery trees. As an illustration, seedlings of *Eremocitrus glauca* grow very slowly for several years and do not reach normal budding size until they are five to six years old. By that time they have developed a very large root system and probably are seriously injured by transplanting. By using a special technique, small seedlings may be grafted, and such grafts exhibit normal unions and grow much better than budlings propagated by the ordinary methods. Nevertheless, how such new stocks can best be used is not known; ordinary nursery methods may be entirely unsuited to their peculiarities.

The tabog (*Swinglea glutinosa*) has been tested as a rootstock in Hawaii, but according to Pope (1934) it has been discarded on account of its slow growth and hard, close-grained wood. Swingle, however (see this work, Vol. I, p. 452), has stated that this species budded to *Citrus* grows well in greenhouses kept at high temperatures. He suggests that it may prove valuable as a stock in tropical regions having high soil temperatures in winter. Here, as elsewhere in the use of such citrus relatives, the methods of propagation must be determined, and also the conditions under which the stock is valuable.

It must be granted that none of these citrus relatives have been sufficiently tested to determine their true value. Some of them are very resistant to salt or alkali injury (*Merope*, *Severinia*, etc.); some have been shown to have a high tolerance for boron (*Eremocitrus* and *Severinia*); others are very drought-resistant (*Eremocitrus*, *Microcitrus*, etc.); and some are very resistant to certain serious diseases—all characters of some importance in citriculture. Some of them, on more extended trial, may be found satisfactory as rootstocks for certain varieties under special conditions. It does not seem probable, however, from the few trials thus far made, that they possess great value for use with the standard citrus varieties in commercial propagation. It seems certain that the main value of these relatives is not to be expected from their direct use as stocks, but from their possession of valuable characters such as resistance to drought, to boron or alkali injury, or to disease, whence they may be used through hybridization to combine with known good citrus stocks in order to produce new hybrid varieties that will possess the special characters desired and be more congenial in their growth factors with standard citrus varieties.

When one first examines the dwarfed trees of citrus varieties budded directly onto such rootstocks as *Eremocitrus*, *Severinia*, or *Swinglea*, the too common tendency is to dismiss as fantastic and wholly impracticable the idea of employing such relatives for rootstocks. It is a problem for the plant breeder to combine their desirable characters in hybrids and thereby to produce successful stocks that will be more resistant to drought and have greater tolerance for alkali and boron. That such shifts of characters can be obtained frequently through recombinations in hybrids is a well-known principle of breeding.

*Swinglea* and *Severinia* are rather remote relatives, and their ability to hybridize with *Citrus* apparently has not yet been demonstrated. *Eremocitrus* and *Microcitrus*, however, are close relatives and have been successfully hybridized with certain species of *Citrus*.

Swingle (see this work, Vol. I, p. 365) has directed attention to the fact that *Eremocitrus glauca*, which has a very high tolerance for boron, produces numerous hybrid seedlings (eremolemons) when grown near the Meyer lemon. The hybrids were found to grow very vigorously and to produce numerous fruits with 1 to 3 seeds each. The seedlings grown from such seed produced plants exactly like the original hybrids, and experimental tests showed that they had inherited the high degree of resistance to boron injury of the *Eremocitrus*. It is quite probable that such hybrids would be more congenial with citrus varieties than the parent *Eremocitrus*, and their high tolerance to boron might give them special value as stocks for use in regions where boron in irrigation water or in the soil renders the use of ordinary stocks dangerous.

There can be no doubt that any citrus relative that is found to possess qualities of high resistance, either to toxic soil chemicals or to disease infection, is likely to prove exceptionally valuable in breeding experiments to produce resistant stocks. It is the writer's belief that this field of research will yet produce results of far-reaching importance.

## RELATION OF NUCELLAR EMBRYONY TO CHOICE OF ROOTSTOCKS

One of the factors of prime importance in the selection of citrus rootstocks is the degree of nucellar embryony shown by different varieties and species (consult Vol. I, chap. ix). Since the seedlings developed from nucellar embryos are produced directly from the tissue of the mother, without the intervention of cross-fertilization, they are likely to be about as uniformly like the mother as they would have been if the propagation had been by cuttings, and they will all show normal root development.

It is clearly of advantage to use a stock variety that will reproduce the type as nearly true as possible by seed propagation. Since the embryos developed by cross-fecundated egg cells are likely to be variable, owing to the commingling of diverse heritage from different parents, it is evident that the larger the number of nucellar embryos developed, the greater will be the proportion of seedlings having the same characters as the mother. Different *Citrus* species and varieties, as recorded by Webber (1900*a*, 1900*b*, 1932*e*), Frost (1926), Toxopeus (1930), and Torres (1936), show considerable differences in the number of nucellar embryos developed. In those producing few nucellar embryos, such as the lemon varieties Eureka and Lisbon, the seedlings would normally be developed mainly from fertilized egg cells; but those producing a large number of nucellar embryos, such as the Rough lemon, would have only few seedlings developed from fertilized egg cells. The uniformity of the seedlings, therefore, will depend largely on the proportion of the nucellar-embryo seedlings developed. (See Vol. I, table 44, p. 794.)

In the reproduction of certain first-generation hybrids, such as the Sampson tangelo and various citranges, it has been found that the seedlings in the second generation come as true to the type of the first-generation seedlings as if they had been grown from cuttings. In one experiment, thirty-seven seedlings of the Sampson tangelo, grown at the California Citrus Experiment Station from fruits taken from a tree open to free cross-pollination, exhibited, at the age of twelve years, when in full fruit, almost no recognizable variation. Likewise, progenies consisting of several hundred seedlings each from the Rough lemon, the Palestine sweet lime, and the Savage, Cunningham, Rusk, Morton, and Coleman citranges, in their early stages up to three years of age, were found to be similarly uniform. Seedlings of the Sanford citrange, however, exhibited great variation; in this variety the fertilized egg cells commonly develop, and nucellar embryony is apparently less frequent or wanting.

In varieties that produce a fairly high percentage of nucellar embryos most of the seedlings can be recognized as representing the largest proportion of the progeny. They will have the same foliage and branching characters and will in general be of about the same size. They present a uniform and, commonly, easily recognizable type. Mixed with these will be a varying number of seedlings that show different characters, such as different branching and larger or smaller leaves, and that are usually less vigorous and of smaller size. These, in large part, are the so-called "variant" seedlings which appar-

ently are mainly produced from gametic embryos resulting from the cross-fertilized egg cell. It is these small, off-type seedlings or variants that should be discarded to obtain uniform seedlings for use as rootstocks.

Toxopeus (1932) found that it was possible to distinguish the seedlings of sexual origin from those of vegetative origin, in what he calls the "Japansche Citroen" (see footnote 1, p. 101), and in the Rough lemon, and by this means to insure the use of a more or less standard stock. He states that in the Rough lemon the sexual seedlings are so distinct that it is unnecessary to describe them otherwise than as generally weak.

## IMPROVING TREES BY SELECTION OF ROOTSTOCK SEEDLINGS*

### LARGEST SEEDLINGS AS PRODUCTIVE OF LARGEST BUDLINGS

In agricultural crops generally, it is considered important to exercise some selection of the plants or seeds used in propagation in order to eliminate inferior individuals. The importance of such selection has been demonstrated by careful experiments. Some selection has been practiced commonly in the propagation of citrus nursery-stock seedlings, but, so far as is known to the writer, no experiments in proof of the desirability of such selection had been made prior to his experiments begun in 1917 (Webber, 1920*a*, 1920*b*). These experiments have been continued up to the present time (1943), but the principal conclusions were published in 1932 (Webber, 1932*e*). As the sour orange was perhaps more generally used than any other rootstock, the world over, the data from the selection tests with this stock are given here in some detail. In considering these results it should be remembered that the percentage of nucellar embryony of the sour orange apparently varies between 70 and 80 per cent, as determined by the writer from the examination of different lots of seedlings.

The writer (Webber, 1932*e*) has shown that, in a lot of 389 unselected sour orange seedlings worked with buds from one highly selected tree of the Washington Navel, the seedlings that were the largest at the time of budding produced, in general, the largest trees. In this lot of trees the area of the cross section of seedling trunk (determined from the circumference 4 inches above the soil, measured just prior to the budding), when compared and correlated with the area of cross section of the one-year-old budling trunks 2 inches above the bud union, gave a correlation coefficient of $+ 0.736 \pm 0.016$, showing that among the young budded trees the large ones had mainly been produced on large stock seedlings. When the same trees were eight-year-old orchard trees (eight years in orchard), a similar comparison gave a correlation of $+ 0.437 \pm 0.028$. These correlations are high enough to show clearly that in an ordinary lot of unselected stock seedlings the size of the seedling at time of budding has a significant influence on the size of the budlings and of the orchard trees.

* The experimental data on which this section is based are included in the following publications: Webber, 1919, 1920*a*, 1920*b*, 1920*c*, 1922, 1923, 1926, 1927, 1928, 1929, 1931, 1932*a*, 1932*b*, 1932*d*, 1932*e*; Webber and Barrett, 1931.

In the same lot of trees, when the size of the one-year-old budlings is compared with that of the eight-year-old orchard trees, a correlation of $+0.622 \pm 0.021$ is found to exist, showing that, in general, the large budlings produced large orchard trees. If large-sized orchard trees are desired, these figures indicate the importance of a rigid selection to eliminate the small seedlings and small budlings in the nursery (fig. 62).

Fig. 62. Washington Navel on sweet orange stocks, showing effect of size of nursery trees on size of trees in the orchard: *right*, row planted with large nursery trees; *left*, row planted with small nursery trees. The trees are all of the same age, from the same seedbed and nursery, and otherwise entirely comparable. California Citrus Experiment Station, Riverside.

## VARIATION IN ROOTSTOCK SEEDLINGS

Irrespective of the species or variety of rootstock used, variations in size such as those that occurred in the lot of sour orange seedlings referred to above will be found to exist. A careful examination of such a lot of seedlings also reveals that there are other differences: in type of branching, length of internodes, form and size of leaf, etc. Size variations are probably due in appreciable measure to environmental and accidental causes, but the other types of variation in seedlings grown in proximity are not likely to be caused by environment. Such variations, in most plants, are more likely to be due to different heritage (genetic constitution) from the two parental lines, commingled in the offspring. In *Citrus*, however, where a high percentage of the seedlings of most good stock types are developed from nucellar embryos,

Fig. 63. Sour orange trees showing variations in size due to individual differences in scions from variant types of sour orange seedlings. Two trees of each type were propagated, one on Rough lemon and the other on ordinary sour orange stock. The trees are thus in pairs, except the dwarfed tree at the left, which is the only one of the pair shown. Extreme dwarf types such as this, when used as stocks, always produce dwarfed trees like the small central tree in figure 64; types such as those shown by trees 4 and 5 from the left always produce strikingly dwarfed trees when budded. Types such as those shown by trees 2 and 3, and 6 and 7, though of more vigorous growth, are abnormal variants and produce some degree of dwarfing, as illustrated by second tree from right in figure 64.

Fig. 64. Eight-year-old Washington Navel orange trees, showing variations in size due to individual differences in the sour orange seedlings used as stocks. All Washington Navel buds used in propagation were taken from one carefully selected tree. The small and medium-sized trees here are on rootstock seedlings of variant types such as those used as scions for the trees in figure 63.

variations due to the crossing of different types are not so frequent. Here a large percentage of seedlings come from nucellar embryos and are likely to be genetically of the same type and thus to exhibit similar characters.

If one studies carefully a field of nursery seedlings of a sour orange variety, it will become evident that the great majority of them, perhaps 70 to 80 per cent of the total, are very much alike and represent a prevailing type. The other 20 to 30 per cent will differ from this prevailing type in various characters, such as reflexed branches, short bunchy growth, smaller leaves, rounded leaves, more pointed leaves, narrower leaves, and the like. These off-type seedlings, which are mainly smaller and apparently weaker than the general run of seedlings of the prevailing or normal type, are designated "variants."

*Nature and importance of variants.*—While the seedlings of the prevailing type are evidently in greater part from nucellar embryos, it is probable that the seedlings of the variant types are mainly from embryos that develop in the normal way from the egg cells after pollination and fecundation, and that these seedlings are therefore genetically different from the nucellar-embryo seedlings of the prevailing type (see Vol. I, p. 842). All these are seedlings of the sour orange, but are all equally satisfactory to use as stocks? (See fig. 63.)

An examination of the lot of 389 nursery seedlings of sour orange referred to above revealed that 43 of them[1] should be classed as variants because of characters, visible in the nursery, differing from the prevailing type. All the seedlings were numbered and budded at the same time with buds from one selected tree of Washington Navel, and the trees were then grown in an experimental orchard. With one or two exceptions, all the trees classed as variants produced orchard trees showing some degree of dwarfing, and most of them produced marked dwarfing (fig. 65).

These variants apparently occur normally among citrus seedlings. Since the majority of them are constitutionally weak and below normal size, a rather large proportion of them die before reaching the age and size for budding. Many are doubtless discarded in the seedbed because they are too small to transplant successfully, but a sizable number of them, if not recognized and discarded, are finally budded and transplanted into orchards, causing irregularities in size (fig. 64) and lowered production.

The fairly high correlation (+0.437) between sizes of nursery seedlings and sizes of eight-year-old orchard trees was caused, in large part, by the presence of these variants. When the 43 variants were excluded and the size of the nursery seedlings, as shown by area of cross section of trunk of the remaining 346 trees, was compared at different intervals with the trunk size of the budlings, the following gradually decreasing correlations were obtained: with one-year-old budlings, $+0.549 \pm 0.026$; three-year-old trees, $+0.125 \pm 0.036$; six-year-old trees, $+0.010 \pm 0.036$; and with eight-year-old trees, $-0.021 \pm 0.037$. In the nucellar-embryonic population, consisting of

[1] This number of variants would indicate only 89 per cent nucellar embryony, but many of the small variants had died before the budding was done, or were too small to bud.

the seedlings remaining after the variants were removed, the small degree of correlation at first existing had disappeared by the end of the sixth year in the orchard. This is corroborated by the fact that with the same population (variants excluded) the correlation of trunk size of seedlings with trunk size of stocks and with volume of tops, of the eight-year-old trees, had fallen to $-0.054 \pm 0.032$ and $-0.012 \pm 0.036$, respectively, indicating that there was no correlation.

The yield of the trees during the first eight-year period does, however, show a low correlation. Here, with the population of 346 trees (exclusive of vari-

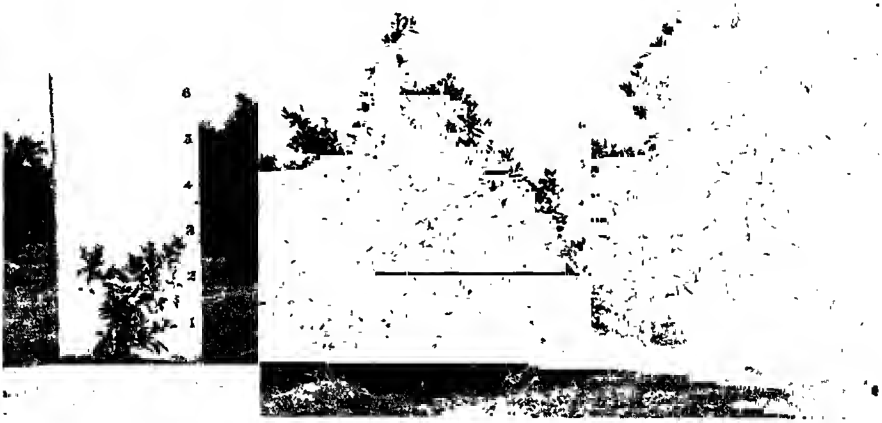



Fig. 65. Comparative size of Washington Navel orange on different seedling rootstocks of sour orange: *A*, extreme-variant sour (no. 52–39), causing marked dwarfing; *B*, medium-variant sour, causing medium dwarfing; *C*, normal sour orange, producing standard-sized tree. All trees nine years old.

ants), when area of trunk cross section of stock seedlings was compared with the total five-year yields of the eight-year-old orchard trees grown on them, there was obtained a correlation of $+0.135 \pm 0.035$. Although this is a positive correlation, it is so low as to be of doubtful significance.

*Importance of eliminating variants.*—In view of the fact that, after the variants are removed, the variation in size of the remaining seedlings shows no significant correlation with the size of the orchard trees at the end of the eighth year, it seems clear that the important factor in nursery selection is removal of the variants. This can be achieved with fair success by discarding the small seedlings when they are dug from the seedbed, and by a further elimination of the small seedlings and variant types in the nursery just before the budding.

### LARGEST BUDLINGS AS PRODUCTIVE OF LARGEST ORCHARD TREES AND YIELDS

With the population of 389 sour orange trees referred to above, the correlation of area of cross section of scion trunks of the one-year-old budlings with

that of the eight-year-old orchard trees gave a coefficient of + 0.622 ± 0.021; a similar correlation for the 346 trees remaining after the variants had been eliminated was reduced to + 0.182 ± 0.034. When, with the entire population of 389 trees, budling size was correlated with total five-year yield of fruit per tree in the eight-year-old orchard, the coefficient was + 0.517 ± 0.025; and with variants removed this was reduced to + 0.233 ± 0.034. It seems that here, even with the variants removed, there is an appreciable correlation between size and yield of orchard trees.

Almost the same correlations were obtained for a population of 1,506 ten-year-old orchard trees of Washington Navel on sweet orange stocks, from which all small budlings had been rigorously eliminated before planting (variants thus removed). Here the area of cross section of scion trunk of the orchard trees, taken one year after planting, correlated with the area of cross section of trunk when nine years of age and with average total seven-year yield per tree, gave coefficients of + 0.158 ± 0.017 and + 0.229 ± 0.016, respectively (Webber, 1932*a*, p. 55).

These results, together with other data, led Webber (1931, p. 116) to conclude: "It thus seems that it is fairly safe to assume that after all variants are excluded from a population a small degree of correlation still exists between budling size and tree size, and between budling size and orchard yield, amounting to a coefficient of approximately + .15 to + .18 in the former, and + .22 to + .23 in the latter. These are positive correlations but are small and thus of rather doubtful significance and leave one somewhat in doubt whether any selection other than that intended to eliminate the variants is important."

### COMPARISON OF SEEDLING AND BUDLING SELECTION

In the experiments with sour orange trees referred to above, detailed records of each tree were retained and it was thus possible to arrange and test the results of different methods of selection (Webber, 1932*b*; 1932*e*, p. 63). Records of the entire population of 346 trees (variants excluded) were used and two methods of selection were tested, one based on the diameter of the stock seedlings just before they were budded, the other on the diameter of the scion trunk of the one-year-old budlings just before they were transplanted to the orchard.

In the selection based on seedling size, seedlings 2.1 cm. or more in diameter were graded as *firsts* or *large*, and those 2.0 cm. or less in diameter were graded as *seconds* or *small*. In the selection based on budling size, a similar classification was employed: budlings having scion trunks 1.8 cm. or more in diameter were graded as *firsts* or *large* (grade one), and those having scion trunks 1.7 cm. or less in diameter were graded as *seconds* or *small* (grade two). The average total five-year yields of all the trees in each grade were then brought together for comparison (see table 9).

An examination of table 9 shows that, when the selection (segregation) was based on diameter of seedling trunk, there were 237 seedlings in grade one and 109 in grade two, and the average five-year yield of trees of grade one was 56.2 pounds per tree greater than that of trees of grade two. When the

selection was based on diameter of budling trunk, there were 242 trees in grade one and 104 in grade two, and the average five-year yield of the trees grown from the grade-one budlings was 47.2 pounds per tree greater than that of trees from grade-two budlings.

The comparative results indicate that selection based on size of seedlings before budding is fully as effective as that based on size of budlings. Furthermore, seedling selection is much less expensive than budling selection, as a discarded nursery seedling is much less valuable than a discarded budling. In either case, however, the value of the extra fruit produced on the selected trees would in a few years pay the costs entailed by the selection.

TABLE 9

COMPARATIVE YIELDS OBTAINED BY SEGREGATING STOCK SEEDLINGS AND BUDLINGS (AFTER ELIMINATION OF VARIANTS) INTO LARGE AND SMALL GRADES*

| Grade | Diameter of trunk (cm.) | Number of trees | Per cent of total population | Total average yield per tree (lbs.) | Gain in yield per tree over second grade | |
|---|---|---|---|---|---|---|
| | | | | | Pounds | Per cent |
| Seedlings: | | | | | | |
| Firsts (large)... | 2.1 or more | 237 | 68.5 | 294 4 | 56.2 | 23 6 |
| Seconds (small)... | 2 or less | 109 | 31.5 | 238.2 | . | .... |
| Budlings: | | | | | | |
| Firsts (large).. | 1.8 or more | 242 | 69.9 | 290.8 | 47.2 | 19.4 |
| Seconds (small).... | 1.7 or less | 104 | 30 1 | 243.7 | | |

* Total population, 346; mean total yield per tree for five-year period, 277.18 lbs.

## PERMANENCE OF IMPROVEMENT OBTAINED BY SELECTION

The elimination of variants is of primary importance in the cultivation of citrus, as trees propagated on variant seedlings remain, with few exceptions, permanently dwarfed and unproductive. This is the fundamental reason for selection.

In the studies reported above, differences in size of trees and in yields, as the result of selection after elimination of variants, were marked during the first few years. Gradually these differences disappeared, though some differences were apparent up to the close of the eighth year in the orchard. The benefit resulting from the selection of variant-free progenies was interpreted by Webber (1932*e*, p. 70) as due to the holdover influence of large size and vigor in the young seedlings, which maintain the advantage for a considerable period. It was not supposed that the heritage of the plants was influenced by the selection, but rather that the effect was similar to that obtained by the selection of large seeds.

Careful studies on rootstock seedling size as it affects the size and yield of orchard trees have also been carried out by Mendel (1940) in Palestine. Mendel used stocks of the Palestine sweet lime budded to Shamouti sweet orange. Four plots of 20 trees each on small or thin stocks and four plots of 20 trees each on large or thick stocks were set out in alternate arrangement in a test orchard, and their comparative development was recorded.

It was found that the difference between the groups of thick and thin stocks, which at the time of the selection in May, 1931, amounted to 43.6 per cent (the diameter of the thick stocks being taken as equal to 100 per cent), decreased gradually until the time of transplanting into the test orchard, in March, 1934, when the difference was only 7.3 per cent. At this time a second selection was made, which raised the difference to 20.5 per cent. Following this, Mendel (1940, p. 84) stated that the difference between the thick and thin stocks was reduced to 5.1 per cent in June, 1939; that the growth of scions, on the whole, showed the same tendencies as that of the stocks; and that the differences between the groups, with regard to yields, were not significant from the first year of fruiting onward. He concluded that the elimination of morphologically deviating types (variants) was therefore all that mattered in the selection of sweet lime stocks.

Mendel's conclusion confirms the writer's findings in his earlier experiments (Webber, 1932*e*, p. 75). It should be remembered, however, that Mendel worked with the Palestine sweet lime, which develops a very high percentage of nucellar embryos and thus reproduces nearly true to type through the seed, exhibiting normally only about 2 per cent of variant seedlings. These variant seedlings are small and weak, and are mostly eliminated in the transplanting from the seedbed to the nursery, or are usually easily detected and eliminated in the nursery at the time of budding. This same condition holds with the Rough lemon, Sampson tangelo, and such citranges as the Morton, Savage, Rusk, and others, the embryos of which are from 98 to 100 per cent nucellar-embryonic. With such stock varieties, selection to eliminate the small number of variants does not seem very important; but with seedling stocks of sweet orange, sour orange, grapefruit, and mandarin varieties, where the proportion of variants may range from 20 to 30 per cent, careful attention to the removal of the variant seedlings becomes highly important. It is the writer's experience, furthermore, that in transplanting seedlings from the seedbed to the nursery, and to some degree in transplanting budlings to the orchard, the small plants are more likely to perish than the larger ones, and that for this reason, also, the small plants should commonly be discarded.

### METHODS OF SELECTION FOR COMMERCIAL NURSERIES

The application in commercial nurseries of the principles of nursery selection discussed in the previous section is fortunately not difficult and requires only careful observation and attention. Selections should be made at three different times: (1) when the seedbed is dug, (2) in the nursery just before budding, and (3) when budlings are dug for planting.

*Selection at seedbed.*—When the seedbed stock is being transplanted, the policy of discarding all small individuals should be rigorously followed. The proportion that should be destroyed will depend upon the degree of variation exhibited by the particular lot of seedlings. If they are grown from seeds taken at random from trees of varying types, as with the "bulk seed" commonly used, it is probable that 20 per cent or more of the total number should be eliminated. If they are grown from seed from selected trees known to pro-

duce fairly uniform seedlings, the percentage of discards should be smaller. If the seed is from such special varieties as the Rough lemon, Palestine sweet lime, Sampson tangelo, or certain citranges in which nucellar embryony is known to insure a fairly true transmission of type, then the percentage of discards at the seedbed may be limited merely to the size that can be properly handled in transplanting. Almost always, however, from 15 to 20 per cent of the total number should be selected out and destroyed.

At this time also, all malformed seedlings, such as extreme cases of "gooseneck" or "bench root," should be discarded.

*Selection at time of budding.*—When the seedlings growing in the nursery have reached the size and age for budding, preferably just before budding is started, the nursery should be carefully inspected, row by row, and all inferior or off-type plants cut out. At this time, also, a considerable number of the small plants should be eliminated. This is the last time that the character of the seedlings can be examined, and it is the most important time to use care and be thorough. If there was a fair elimination at the seedbed, this selection should not require the destruction of more than perhaps 5 to 10 per cent of the total number of the plants.

*Budling selection.*—When the budded trees have reached the age and size for transplanting, they will vary considerably in size, owing to differences in the manipulation, in the time the buds started growth, etc. If, however, the seedling stocks have been carefully selected, as indicated above, all should produce good trees, except, rarely, where the buds did not heal on well or were defective. At this time all particularly undersized, weak, or sickly budlings should be discarded. With properly selected seedling stocks and good buds the elimination at this time will be slight, probably not more than 5 per cent. Even at this time the trees have a low value in comparison with the value they will have after a few years in the orchard, and the importance of having every tree a good tree, in a long-time crop like citrus, can scarcely be overestimated.

## USE OF SPECIAL ROOTSTOCK VARIETIES

*Earlier inquiry with respect to species.*—Until very recently, attention given to rootstocks has been limited almost wholly to a consideration of species reactions only. The inquiry has been directed toward determining whether it is best to use stocks of sour orange, sweet orange, grapefruit, or some other species. The only exception is the use of certain varieties such as the Rough lemon, Palestine sweet lime, Cleopatra mandarin, Sampson tangelo, and a few others, which, because of their outstanding characters, came to be tested and finally used as stocks under their varietal names.

*Present interest in varieties.*—It is a well-recognized fact that all species are variable and that the species of *Citrus* under general cultivation have developed many very distinctly different varieties and strains. As an illustration, in the stock experiments of the California Citrus Experiment Station there are now some fifty different types or varieties of the sour oranges that are fruiting. At twenty years of age, these trees grown as seedlings or as budded trees on uniform stocks range in height from 5 to 18 feet and are

equally different in fruit and foliage characters (see this work, Vol. I, p. 486.) It is inconceivable that these different types would give like results when used as stocks, yet all of them are sour orange. It has been found that many of these types, when tested with the same strain of the Washington Navel, give markedly different results, the scion tops showing almost as great a range in size as the stock types themselves (see fig. 64). Rootstock experimentation hereafter should be directed toward finding the best stock strains among the numerous varieties of each promising stock species.

*Choice of stock strain for best bud strain.*—In the rootstock tests at the California Citrus Experiment Station some evidence has been obtained indicating that, with the same scion strain, certain varieties give better results as stocks than certain other varieties of the same species. The trees of Owari Satsuma on African sour orange rootstocks were markedly inferior to those on other sour orange stocks, especially the Brazilian; and again in the tests with scions of orange, grapefruit, and lemon varieties, the African sour was usually inferior to the other sour stocks tested, though not always to a significant degree. The Cleopatra mandarin was usually, but not always, better than the Dancy. Eureka and Lisbon lemon scions on Bessie, Madam Vinous, and Koethen sweet orange stocks in general gave better results than those on the Homosassa sweet (see data in chap. iii). The same seemed more or less true of different sour orange, grapefruit, and mandarin stocks used with a uniform bud strain (Webber, 1934). Usually, however, these differences were small and of doubtful significance, but occasionally they were consistent and fairly large.

These experiments included only a few (3 to 6) rootstock varieties of any single species, and these were always chosen as strong, vigorous growers. Among so small a number, so chosen, no great range of difference would be expected. If a large number of stock varieties of the same species were to be tested, it seems certain that a wide range of significantly different yields would be obtained, and that there would be differences also in resistance to disease, length of productive life, and other factors. The writer bases such a statement not only upon the limited experimental evidence available, but also upon the general results obtained by those who experiment in the breeding of plants and animals.

According to the evidence available, if the same reaction is to be expected regularly, the stocks must all have the same genetic constitution, and the scions, also, must be of the same strain and genetically homogeneous. By determining the reactions of genetically homogeneous strains, one should be able to discover the most satisfactory combination of stock and bud strain, and thus be able to reproduce the same favorable reaction regularly. Only in this way, apparently, can there be any certainty in expected results. In the California Citrus Experiment Station tests, for instance, it has been shown that the Sampson tangelo is a good stock for the Valencia orange but inferior for the Washington Navel (see pp. 184–185, 187, 190). In the future, study should be directed to variety and even to strain congeniality instead of to species congeniality only.

## IDENTIFICATION OF ROOTSTOCKS

### DIFFERENCES IN CHARACTER OF FOLIAGE AND OF BUD UNIONS

It is frequently desirable to identify the rootstocks of trees, but until recently no satisfactory method of identification has been known. The quickest and surest method of identifying a rootstock is by examination of sprouts from the stock. Anyone familiar with *Citrus* species can usually identify the different ones by the foliage or the odor of the crushed leaves. Frequently, however, no sprouts are formed on the stock, and several years might be required to induce them to develop.

A fairly correct diagnosis of the stock species may often be made by observing the stionic reaction at the bud union, as pointed out by Webber (1927). Extreme reactions in different combinations may somewhat overlap, however, so that with individual trees on mixed stocks errors will frequently be made (see discussion of stock reactions, p. 73).

### DIFFERENCES IN STEM AND ROOT STRUCTURE

Differences in cellular structure have been effectively used to distinguish a limited number of stock species. Penzig (1887) found a striking difference in the cellular structure of the pith of twigs of trifoliate orange and sour orange, and Swingle (1909) suggested this method of distinguishing between these two species when used in Satsuma production. Longitudinal sections of the pith of young stems of the trifoliate orange exhibit an irregular arrangement of thin-walled cells together with crossplates of thick-walled cells (figs. 66, *A*, and 67), while similar sections

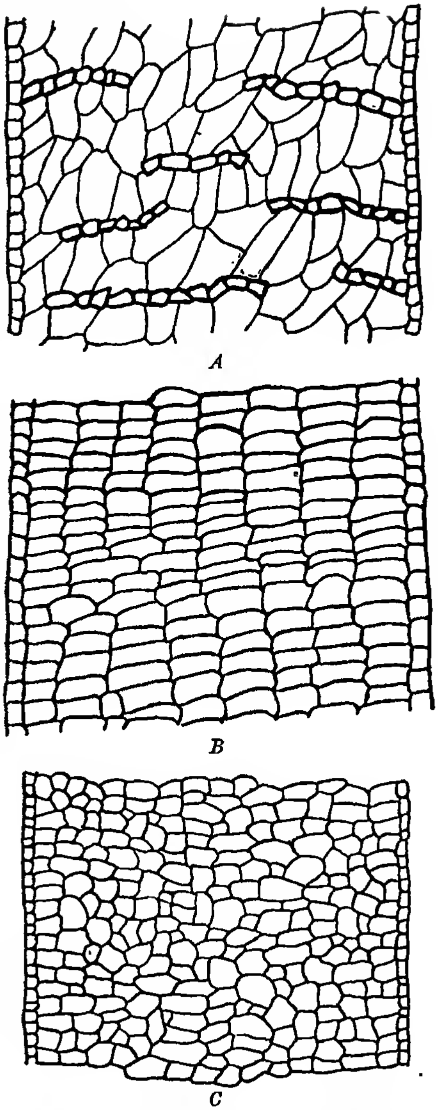



Fig. 66. Cellular structure of different citrus species, as shown in longitudinal sections of pith of young stems: *A*, trifoliate orange, showing crossplates of thick-walled cells and irregular arrangement of thin-walled cells; *B*, sour orange, showing arrangement of cells in series; *C*, yuzu orange, showing irregular arrangement of cells, without crossplates. (After Wolf, 1912.)

of the pith of sour orange stems show only uniform thin-walled cells arranged in regular series, and an entire absence of the crossplates of thick-walled cells (fig. 66, *B*). Wolf (1912) extended this method to distinguish the yuzu orange, which was found to have only thin-walled pith cells similar to those of the sour orange but irregularly arranged (fig. 66, *C*). It thus differs from the sour orange, in which the cells are arranged in regular series or chains, and from the trifoliate, in which there are crossplates of thick-walled cells.

Wolf also studied characteristic differences observable in cross sections of one-year-old roots (about 4 mm. in diameter) of the same three species (fig. 68). The trifoliate orange is easily distinguished from the sour orange and the yuzu by the large vessels in the wood, these being much larger and more numerous than similar vessels in the other two species, and by the more numerous groups of bast fibers in the bark, which form three or four broken concentric rings. In the yuzu, only a few scattered groups of bast fibers are present in the bark, whereas in the sour orange the groups of bast fibers are numerous and close together in the inner row, with only a few scattered groups farther out, a condition intermediate between that of the yuzu and the trifoliate orange, but clearly differentiating the sour (fig. 68).

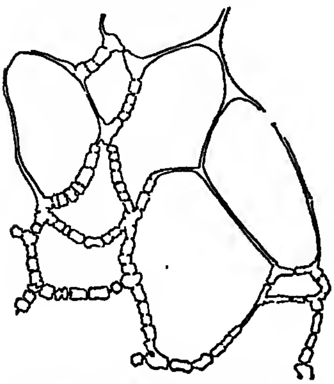


Fig. 67. A small group of thick-walled cells from pith of trifoliate orange. Magnified 375 diam. (After Swingle, 1909.)

In the differentiation of trifoliate stock from the yuzu, Wolf also found that the yuzu roots, when bruised, emit a strong, penetrating odor, disagreable to many, and that the odor of trifoliate is faint and milder.

## DIFFERENCES IN COLOR REACTIONS WITH CHEMICAL REAGENTS

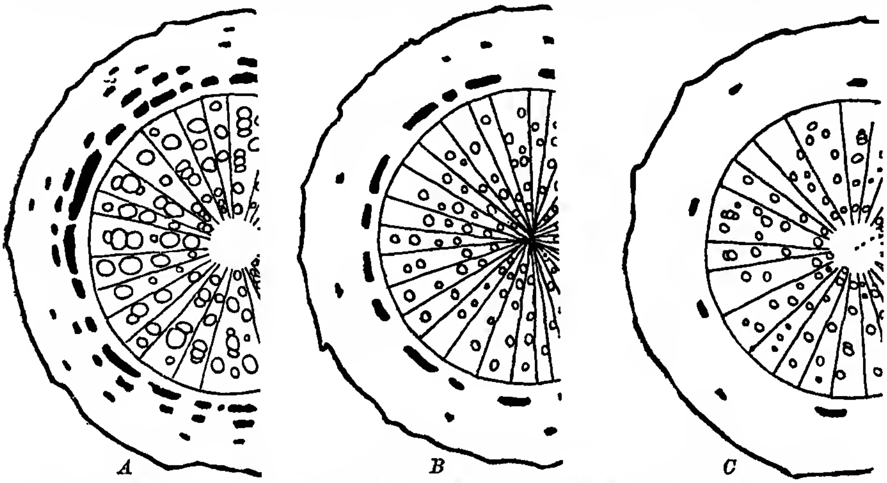
The first attempt to identify stocks by colorimetric chemical reactions was apparently that made by Henricksen (1928), of the Puerto Rico Agricultural Experiment Station, who based his method on the presence in all citrus roots of varying quantities and kinds of glucosides containing phenol. He used extracts from the root tissues and, with ferric chloride as an indicator, found that the different color reactions obtained were more or less characteristic of the species.

Halma and Haas (1929*a*, 1929*b*) developed a similar method of identifying citrus species by employing colorimetric chemical tests with samples of dried bark. A number of tests were used in these experiments, but the one that gave most consistent results was the Almén test (Cohn, 1909, p. 3) for carbolic or salicylic acid, which is practically the same as Millon's reagent for albumens and phenols. Their experiments also indicated that three other reagents—molybdic acid, titanous acid, and ferric chloride—were of value when identification was doubtful. The results obtained by these investigators were sufficiently uniform within commonly accepted limits of the species to lead them

to "suggest the possibility that these colorimetric differences may be useful in citrus classification."

In a later paper, Halma (1934, p. 102) described the preparation and use of the Almén test as it had been modified since its first use by Halma and Haas. This modified statement follows:

Enough bark is lifted from the rootstock trunk to make at least 0.5 grams when dried at about 70° C. After drying it is ground fine enough in a mortar to pass through a 40-mesh sieve. 0.5 grams of this powder is placed in a beaker and 20 cc. of distilled water is added. After several minutes the contents of the beaker are transferred to filter paper and the



A B C

Fig. 68. Diagrammatic cross sections of roots of citrus species, illustrating the characteristic arrangement of groups of bast fibers in the bark, and the comparative size and arrangement of large vessels in the woody cylinder: *A*, trifoliate orange; *B*, sour orange; *C*, yuzu orange. (After Wolf, 1912.)

residue washed with 10 cc. of water. The 0.5 grams of powder are therefore leached with 30 cc. of water, and 5 cc. of the filtrate are made alkaline with two drops of potassium hydroxide prior to adding 10 drops of a saturated solution of copper sulphate. This is followed by 10 drops of mercury reagent which is made up as follows: 160 grams of re-distilled mercury are dissolved in 160 grams of red fuming nitric acid (specific gravity 1.60) and this is finally diluted with 320 cc. of distilled water. 10 drops of this reagent are added to the contents of the test tube and boiled. The resulting colour of the solution identifies the variety. Thus the sour orange bark extract assumes a sort of amber colour and that of the sweet orange a dark pink. The Eureka lemon, although not ordinarily used as a stock, can easily be distinguished from the sour orange by a reddish colour reaction. These two varieties can be further separated by adding two drops of ferric chloride solution to 5 cc. of bark extract. In this test the Eureka lemon extract turns a blackish brown and the sour orange a much lighter brown. (Tests with Rough lemon bark extract show that its colour reaction is distinctly different from that of the Eureka lemon although both varieties are classified as *Citrus limonia.*) Although the nature of the colour reactions has not been investigated it has been found that with budded trees it is not influenced by age of tree, time of year at which the bark sample is taken, and most important of all, the substance involved in these tests apparently does not move across the bud union.

Marloth (1936), in South Africa, has made extensive studies and experiments on the use of these four colorimetric reagents in identifying *Citrus* species, working mainly by the methods suggested by Halma and Haas (1929*a*).[1]

The color reactions obtained by the investigators cited above, for the principal citrus species, are presented in table 10. The four authors agree, in general, that where two species give approximately the same reaction with one of the reagents, they can usually be separated by one of the other reagents. One evidence of the value of such tests, indicated by both Halma (1934, p. 102) and Marloth (1936, p. 7), is the markedly different reactions given by the typical lemon (Eureka and Lisbon) and the Rough lemon, although both are commonly classed as the same species, *Citrus Limon*. However, it has long been recognized by all students of *Citrus* that the Rough lemon is doubtless a hybrid, though its parentage is still unknown (consult Vol. I, p. 607). Marloth (1936, p. 7) also directs attention to the different reactions of the pummelo (shaddock) and grapefruit, which are frequently classed as the same species.

Bacchi (1943) used these colorimetric tests in Brazil to identify rootstocks in the study of the tristeza disease (see p. 100). He found the Almén and ferric chloride tests to be the most satisfactory, permitting the separation of the species and varieties into four groups: (1) *Citrus Aurantium,* (2) *Citrus sinensis,* (3) *Citrus Limon,* and (4) "all the others." The reactions obtained were somewhat different from those given above, and it was suggested that this was perhaps due to the variation in the environmental conditions.

It is evident that these colorimetric tests may serve a useful purpose as an aid in determining the identity of stocks, where such information is desirable, and also that they may supply additional evidence on the relationship of species. It is probable, as Marloth suggests, that the tests may become more reliable when the actual source and cause of the reactions have been determined.

## INTERSTOCKS IN DOUBLE-WORKED TREES

Within recent years, experiments have been made with deciduous fruit crops to gain information on the use of interstocks (intermediate stocks) and the influence they exert. Thus far, however, little attention has been given to the use of interstocks in citrus culture, and apparently no results from carefully planned experiments have been recorded. Occasionally, in every citrus section, the trees in an orchard, or a few trees, are top-worked to a different variety of citrus, and the information now available on the problem of interstocks is almost entirely limited to observations on such trees. Old trees that have established large root systems probably require a fairly long time to show the influence of the new combination, and the reactions shown by such trees may be expected to differ more or less from those shown by interstock trees of the same combination propagated in the nursery.

[1] For details with reference to the preparation and use of these reagents (Almén solution, ammonium molybdate, titanous chloride, and ferric chloride) consult Halma and Haas (1929*a*). For each of these tests the bark extract is prepared as described above.

TABLE 10

COLOR REACTIONS OF BARK SAMPLES OF CITRUS SPECIES WITH FOUR REAGENTS
(Initials in parentheses indicate the authority) *

| Species | Almén test (modified) | Ammonium molybdate test | Titanous chloride test | Ferric chloride test |
|---|---|---|---|---|
| Citron (*C. Medica*) | Very light brown (M) | Dark green (M) | Light brown (M) | Brown, clear (M) |
| Lemon (*C. Limon*) | Rusty red (H & H)<br>Reddish (H)<br>Dark brown (M) | Green (M) | Dark green (M) | Blackish brown (H)<br>Dark brown, clear (M) |
| Rough lemon (a hybrid?) | Very light pink (H & H)<br>Almost colorless (M) | Deep blue (H & H)<br>Deep blue (M) | Light pink (H & H)<br>Almost colorless, pink tint (M) | Straw color, clear (H & H)<br>Light straw-brown, clear (M) |
| Tangerine (*C. reticulata*) | Almost colorless (M) | Light blue (M) | Almost colorless, pink tint, turbid (M) | Light brown, turbid (M) |
| Pummelo (*C. grandis*) | Almost colorless, purple tint (M) | Light blue (M) | Almost colorless. brown tint (M) | Light brown, slightly turbid (M) |
| Grapefruit (*C. paradisi*) | Light pink (H & H)<br>Light brown to pink (M) | Light blue or bluish gray (H & H)<br>Light green, blue-gray tint (M) | Warm gray (H & H)<br>Very light brown-gray (M) | Clear straw color (H & H)<br>Straw-brown, clear (M) |
| Lime (*C. aurantifolia*) | Light pink (M) | Blue, slightly turbid (M) | Almost colorless (M) | Light brown, clear (M) |
| Sweet orange (*C. sinensis*) | Pink (H & H)<br>Dark pink (H), Pink (M) | Green (H & H)<br>Green (M) | Greenish (H & H)<br>Light straw-green, turbid (M) | Brownish, turbid (H & H)<br>Brown, turbid (M) |
| Sour orange (*C. Aurantium*) | Brown (H & H)<br>Amber (H)<br>Light brown (M) | Green (H & H)<br>Light green (M) | Greenish ( H & H)<br>Light brown-green (M) | Dark brown, clear (H & H)<br>Light brown (H)<br>Brown, clear (M) |
| Trifoliate orange (*Poncirus trifoliata*) | Almost colorless, green tint (M) | Green (M) | Almost colorless, brown tint (M) | Brown, clear (M) |

* Data taken from Halma and Haas (H & H), 1929*a*; Halma (H), 1934; and Marloth (M), 1936.

In top-worked trees the interstock comprises the entire trunk between the bud union with the rootstock and the crown limbs. If the use of interstocks were to become common, the length of the intermediate stock would be an important factor, for in the purposeful propagation of interstock nursery trees the tendency would be to shorten the length of the trunk stock, and this might have a marked influence.

Interstocks are generally used for one or more of the following reasons: (1) the prevention or reduction of the injurious effect of a bad union between a stock and a scion which are not congenial, but which, for some reason, it may seem important to use; (2) the prevention of injury from some dangerous trunk disease, through the use of a resistant interstock trunk; or (3) the improvement, in tree growth or in fruit quality or yield, of some character which the interstock is supposed to influence. That some of these effects can be produced in citrus by an interstock seems to have been demonstrated, but the data available are as yet too meager to permit very definite conclusions.

*Reducing the injurious effect of uncongenial unions.*—There is evidence to indicate that the early decline of lemon trees on sour orange stocks, which so commonly occurs in California, may be avoided in some degree—perhaps almost altogether—by the use of an intermediate trunk of sweet orange or grapefruit.

Mertz[1] has described two groves in Orange County, California, in which navel oranges on sour orange stocks had been top-worked to lemon. These trees, in mature bearing age, were much more vigorous than a number of interset replacements made with standard trees of lemon worked directly on sour. The trees with the navel orange "sandwiches" (interstocks) kept their green color much better than the interset lemon trees with lemon trunks (no interstocks). This may have been due, at least in part, to the absence of shell-bark disease on the resistant sweet orange trunks, as this disease was very pronounced on the older trees with lemon trunks. In 1941, when the roots of the "sandwich" trees were forty-five to fifty years old, and the lemon tops twenty-six years old, Mertz states that "they were still in more vigorous shape than any surrounding lemon groves with conventional lemon trunks."

Mr. Mertz also describes a very poor grove of Thomson Navel oranges on sour stocks, planted about 1912 on light sandy soil at Upland, California. About 1924 this worthless five-acre grove was top-worked to Eureka lemon. An adjacent five-acre grove of Eureka on sour orange rootstocks, with the usual lemon trunks, and under the same management, provided a good comparison. For the past ten years (1933–1943) this check grove has shown serious decline, whereas the block with the sandwich trunks of Thomson Navel is vigorous, uniformly green, and thick-foliaged.

In order to avoid the danger of gummosis in the heavy soils of Orange County, California, Mertz states that in some groves under his charge he used for replants nursery trees on sour orange stocks budded to Valencia orange and then top-worked (in the nursery) about 30 inches high to lemon. After an

[1] W. M. Mertz; letter of March 1, 1943, to H. J. Webber. Mr. Mertz was for many years a member of the staff of the University of California Citrus Experiment Station.

examination of these trees in 1941, eighteen years after planting, Mertz (in his letter of March 1, 1943) summarizes the results thus: "The check-up showed a vastly increased vigor as compared with normal lemon trees on sour stocks planted one year earlier. In fact they were much more vigorous than even the best old trees on sweet orange rootstocks. In the sandwich [interstock] trees both unions were very smooth and the tops showed no evidence of decline. Thus, so far as I have observed, the use of sandwich lemon trees gives great promise as a means of retaining the sour orange as a rootstock to employ on heavy soils for lemons."

According to Mertz, a small grove near Upland, California, which was planted about forty years ago to tangerines on sour stocks and top-worked some twelve years ago to lemon, has made very satisfactory growth and has given good yields.

Another illustration of the influence of a sweet orange interstock on Eureka lemon tops is described by A. D. Shamel,[1] of the U. S. Department of Agriculture. In a citrus ranch at Corona, California, certain blocks were planted in 1903, some with nursery trees of Washington Navel orange on sweet orange stocks and others with nursery trees of Eureka lemon on sweet orange stocks. Two or three years later two blocks of the Washington Navel trees were top-worked to Eureka lemon; these trees thus had interstock trunks two to three feet long of Washington Navel.

Shamel has followed the development of these two types of trees since 1909, and during one five-year period he kept careful performance records on comparable lots of trees of both types. In general, the trees with Washington Navel interstocks remained slightly smaller than the others, and the yield throughout the first fifteen to twenty years was slightly less. There was no observable difference in the commercial quality of the two lots of fruit during the period of special study. In recent years the trees with navel interstocks have given rather better yields than the others, but the most conspicuous difference between the two lots has been the resistance of the navel interstock trees as contrasted with the decline of the lemon trees. In the blocks of Eurekas budded directly on the sweet rootstocks a rather large acreage has been replanted because of the decline of the trees, but none of the interstock trees have been replaced.

Shamel wrote: "I believe that the top-worked trees with the Washington Navel 'sandwiches' under our observation, are now the better trees, both from the standpoint of vegetative vigor and fruiting. It is certain that the rebudded trees [top-worked] have not shown the striking evidence of lemon decline which has been conspicuous in the comparable nursery-grown trees [not top-worked]."

Two top-worked groves in the Santa Paula section of California have been kept under observation by Jensen.[2] These groves, one Valencias and the other Washington Navels, both on sour orange stocks, were top-worked to Eureka lemon, and both are reported as fairly successful, producing orchards.

[1] Letter of May 1, 1943, to H. J. Webber.

[2] C. A. Jensen, Manager, Limoneira Company, Santa Paula, California; letter of March 5, 1944, to H. J. Webber.

Lombard[1] has described a Washington Navel orange grove budded on sour orange stocks at the Rancho Sespe, Fillmore, California. This grove was planted in 1928, and in 1933 was top-worked to Eureka lemon. The trees, ten years after top-working, are in excellent condition.

Of interstock trees on the Leffingwell Ranch, Whittier, California, McBeth[2] states: "We have several acres of trees on our property, some lemon and some Valencia, which contain orange or grapefruit sandwiches; however, these trees are all on sweet root. I have observed these trees for many years, and I am not able to say that the sandwich has been either detrimental or beneficial so far as the vigor of the tree or productiveness is concerned." Here, since the sweet rootstock is known to be fully congenial with the scion, as well as with the interstock varieties, no detrimental influences would be expected, but rather perhaps some benefit in the lemon tops because of having interstocks resistant to shell bark.

Many other groves in which interstocks of sweet orange or grapefruit have been used to insure a better congeniality between the sour stock and the lemon top have been reported to the writer; but, although the results are considered satisfactory, the trees are as yet too young to supply reliable evidence. It may be concluded, however, that where it seems desirable to choose sour orange stocks for a lemon planting the use of an interstock trunk of sweet orange or grapefruit would probably be desirable.

It is well known that the sour orange is not a satisfactory stock for the Satsuma, the trees very commonly dying at an early age. However, Robinson[3] wrote: "I saw some well fruited old Satsuma orange trees near Interlachen, Florida, which were grown on the sour orange rootstock, but had a sandwich of sweet orange wood. They were reported to have been satisfactory bearers for many years."

In experiments in Java, in an attempt to prevent the early decline and death of sweet orange trees, Toxopeus (1936) used the Japanese citron (a hybrid?) as an interstock. This stock, which is congenial to both the sweet and the sour orange, was found to have no effect in delaying or preventing the decline, however. Trials of all possible combinations of the three varieties or species were made, and it was found that the trees die only when the scion is sweet orange and the interstock or rootstock is sour orange (see p. 101).

Where the relationship between two species is so distant that a direct union between them fails, the use of a mutually more congenial interstock may serve to promote growth. Swingle,[4] in experiments with the wampee (*Clausena Lansium*), found that Rough lemon buds on this stock grew readily for twelve to fifteen years, even though the union was not particularly good. Grapefruit buds, on the other hand, failed to grow on wampee stock, except with Rough

[1] T. A. Lombard, Assistant Manager, Rancho Sespe, Fillmore, California; letter of March 11, 1943, to H. J. Webber.

[2] I. G. McBeth, The Leffingwell Company, Whittier, California; letter of March 18, 1943, to H. J. Webber.

[3] T. R. Robinson, Senior Physiologist, U. S. Department of Agriculture; letter of March 8, 1943, to H. J. Webber.

[4] Dr. W. T. Swingle, of the U. S. Department of Agriculture; conversation with the writer.

lemon as an interstock. Though the grapefruit tops in such a combination remained small and dwarfed, the trees grew and fruited for many years. To achieve this development of the trees, it was found necessary to let sprouts of the wampee grow from the stock (see p. 72). These sprouts were kept small, however, for if they are allowed to grow too large the grapefruit top suffers and ultimately loses nearly all its leaves.

*Prevention of trunk diseases by use of resistant interstocks.*—The lemon disease known as "shell bark," or "decorticosis," which causes serious damage on many old lemon trees in California, is principally limited to the trunks and main branches. It is probable that the use of an interstock trunk of a resistant variety such as sweet orange or grapefruit would effectively prevent the injury caused by this disease. Mertz, in a case described above (p. 154), attributes a part of the benefit derived from the sweet orange interstock to its freedom from shell bark.

*Influence of interstock on fruit quality and yield.*—According to Robinson (1934, p. 112), tangelos grown directly on Rough lemon stocks tend to produce fruits which become puffy and coarse soon after reaching maturity. However, where grapefruit or orange trees on Rough lemon stocks are top-worked with tangelos there is no such marked influence and the results are generally good.

Robinson has also stated: "There has been a good deal of top-working in Florida, particularly of seedy grapefruit varieties to Temple oranges or to tangelos and the result has generally been very satisfactory. In most cases these grapefruit trees were originally budded on Rough lemon rootstocks. The Temple orange [a tangor], and the tangelos as a class are not a success when propagated on the Rough lemon rootstock, producing a large percentage of coarse semi-dry, pithy fruit. When the same rootstock is used for these varieties but with a sandwich of grapefruit or sweet orange the resulting crop does not suffer the defects referred to."

### DOUBTFUL OR UNSATISFACTORY INTERSTOCKS

Once, when lemon growing in California became unprofitable for a time, a rather large number of lemon groves were top-worked to orange varieties. The writer made observations in one such grove in the San Gabriel Valley section of southern California. This grove was originally composed of blocks of Eureka and Lisbon lemon on sour orange stocks, but the trees in each block had been top-worked, some to navel orange and others to Valencia orange. About fifteen years after the top-working, when the trees were examined by the writer, the Washington Navels with Eureka lemon trunks (interstocks) were all rather poor trees, and those with Lisbon lemon trunks, although distinctly better, were not satisfactory, good trees. The Valencias with Eureka lemon trunks were somewhat better than the navels of the same combination, and the Valencias with the Lisbon lemon trunks were fairly good trees, apparently nearly normal, or as good as would be expected if the Valencia had been budded directly on the sour stock.

A grove in the Tulare County section, composed of Eureka lemon on sour orange stocks top-worked to Washington Navel, was also studied by the writer

when the tops were approximately eighteen years old. This grove had never been fully satisfactory after the top-working, and the trees, when examined, were variable and mainly in poor condition. Trees of this combination—sour stock, Eureka lemon interstock, and Washington Navel top—have also been examined in several other locations, and none has been observed to be in fully satisfactory condition after a period of ten to fifteen years following the top-working. Dr. H. S. Fawcett, Plant Pathologist at the California Citrus Experiment Station, has told the writer of a navel grove of this combination which, though in poor condition when examined, was reported by the owner to have been a good producing grove. John C. Perry, of Highland, California, a very keen observer, writes:[1] "The performance of lemon interstocks is too well known to require my comment. The navel orange tops are dwarfed, bear well while young, but when the lemon bark becomes affected with decorticosis [shell-bark disease], as it almost surely does sooner or later, the double handicap severely weakens the foliage. We have pulled out many such trees and replanted." And D. S. Bell,[2] a highly successful grower, of Riverside, California, has informed the writer that he has under his supervision and observation several groves of Thomson Navel orange on sour orange stocks with lemon interstocks. The trees grow slowly and are hardly larger than they were twenty-five years ago, but "they continually and regularly bear a good crop of fruit." While the evidence is contradictory, it is the writer's conclusion that this combination in top-working (that is, sour rootstock, with lemon interstock and sweet orange tops) is likely to prove unsatisfactory, especially when the interstock is Eureka lemon.

### SUCCESSFUL INTERSTOCK COMBINATIONS

An old top-worked grove of the combination sour orange stock, Mediterranean Sweet orange interstock, and Washington Navel top, studied at one time by the writer, was graded as being in good condition and satisfactory. In this combination the interstock, as well as the top, was of sweet orange, and as sweet orange is commonly successful on sour orange stocks, the combination probably could be expected to prove successful. This is confirmed by Perry,[3] who states that the sweet orange varieties Mediterranean Sweet, and St. Michael, used as interstocks, seem to cause no variation in the performance of navel orange tops. Perry also states that grapefruit interstocks apparently produce normal tops, but that the grapefruit part of the trunk usually grows larger than either the rootstock or the scion at the bud unions.

In concluding this very inadequate discussion of interstocks the writer wishes to state again that the evidence available is too meager to justify definite conclusions. Attention should be directed to the condition introduced by the rapidly expanding knowledge of virus diseases and their common spread by budding propagation. The employment of interstocks increases the possibility of infection with such diseases.

[1] Letter of March 4, 1943, to H. J. Webber.
[2] Letter of March 3, 1943, to H. J. Webber.
[3] J. C. Perry; letter of March 4, 1943, to H. J. Webber.

## RECOVERY OF TREES ON UNSATISFACTORY ROOTSTOCKS

Sometimes after an orchard is planted it is found that certain trees have been propagated on uncongenial or unsatisfactory stocks. When such trees begin to decline or "go back," it would seem that they could be recovered by inarching,[1] into the scion above the bud, seedlings of some good stock type planted at the base of the original tree. This method is frequently used with fair success to save trees that have been girdled or severely injured by rodents or by such diseases as foot rot or collar rot. However, when the decline or failure of trees is apparently due to propagation on unsatisfactory stocks the matter is complicated and recovery does not always follow inarching with good stocks.

One of the most successful experiments of this kind that has been recorded was carried out by the Imperial Horticultural Experiment Station, Okitsu, Japan (1925). In this experiment, 112 Thomson Navel orange trees which had been grafted onto trifoliate orange stocks in 1910 remained much dwarfed and after several years began to decline. In 1917, when the trees were seven years old, 96 of them were inarched with seedling rootstocks of several citrus varieties, namely, yuzu orange, sweet orange, sour orange, Japanese Summer orange (*C. Aurantium* Linn. subsp. *intermedia* Tanaka), and trifoliate orange. In 1925, eight years after the inarching, the results obtained by the use of the different rootstocks were reported. The summary of the results is worth repeating in full:

1. Trees inarched with Yuzu orange show the best results; they have grown in spreading habit quite vigorously with compact shoots and their fruits are superior in quality.

2. Sweet orange stocks gave the best results next to Yuzu, but their characteristics in detail have not appeared till now.

3. Trees inarched with sour orange or Japanese summer orange show in general a very lively growth, but their yields are poor and fruits of inferior quality.

4. Trifoliate orange is unfit as the inarching stock for the purpose of recovering a decadent Thomson Navel orange tree; it stimulates the tree a little for about two or three years after inarching, and after that the influences will fade down.

5. From the results of this experiment and other observations, it can be expected that Yuzu orange would be the most suitable nursery stock for Thomson Navel orange and also for other slow-growing oranges. [See fig. 69.]

Halma (1932, 1938) has described experiments in attempting to improve decadent or declined Eureka lemon trees, supposedly affected by uncongenial sour orange stocks, by inarching them with different rootstocks. The seedling stocks used for inarching different trees included sweet orange, sour orange, grapefruit, pummelo, Rough lemon, mandarin orange, and trifoliate orange. Three seedlings of the same rootstock were used on each tree, and both good and bad trees were treated for comparison. At the end of six years after the treatment no material improvement in the condition of the trees could be observed; the bad trees still remained bad, and the good trees still remained good. It was then concluded that the decline was possibly due to the use of

[1] Methods of inarching are described in chap. i, p. 44.

buds of weak, poor strains in propagating the decadent trees. To test this, good stocks were chosen and budded, some with scions cut from the typical declined trees and others with scions from the good trees. These young trees soon exhibited marked differences in their growth: those propagated from buds taken from the declined trees grew slowly and lacked vigor, while those propagated from the good trees grew much more rapidly and were more vigorous and healthy in appearance. Halma concluded that the decline was due, not to the rootstock, but to the use of budwood from poor strains lacking vigor, and thus could not be greatly improved by changing the stock. It should be noted also that Halma tested some of these trees by girdling them and thus killing the

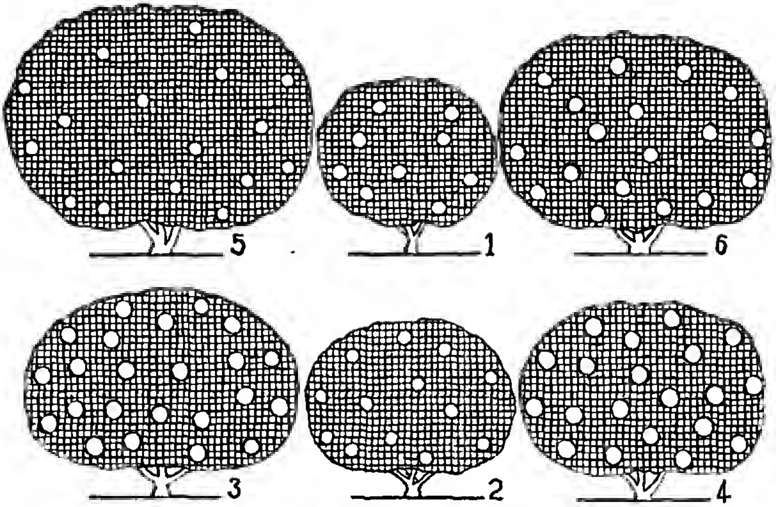



Fig. 69. Inarched Thomson Navel orange trees. Diagram representing comparative average size and shape of trees, size of fruits, and number of fruits (for a three-year period) eight years after inarching: 1, check trees on trifoliate orange stock, not inarched; 2, inarched with trifoliate orange; 3, inarched with yuzu orange; 4, inarched with sweet orange; 5, inarched with sour orange; 6, inarched with Japanese Summer orange. (Reproduced from Imperial Horticultural Experiment Station, Okitsu, Japan, Res. Bull. 4, fig. 1, p. 28.)

original stocks after the inarches were well established, but this additional treatment had no material effect on the recovery of the trees so treated.

In the writer's experiments (unpublished) a similar but very different case has been studied. Some buds of a carefully chosen superior type of the Washington Navel orange were budded to good sour orange stocks and grew into good normal trees. Others of the same lot of buds taken from the same tree were propagated on seedlings of variant types of the sour orange; these buds produced trees dwarfed in size, usually markedly so, and sickly in appearance (Webber, 1932*e*). A number of these dwarfed trees were inarched, when about ten years old, with sour orange seedlings of good rootstock types, but none of them have shown clear evidence of recovery after eight years although most of

them are still living. It might be assumed that, in this case, the variant sour orange stock carried some disease which was transmitted to the scion and caused its continued dwarfish diseased growth, even after the inarching with the good stocks. To test this possible cause, buds were cut from the tops of a number of the dwarfed trees and ten of each were inserted and grown on known good sour orange stocks. Over a period of two years all these budlings showed entirely normal, vigorous, and healthy growth, indicating that no disease had been communicated to them. This suggests that some substance, perhaps a growth-controlling hormone, is produced in the variant rootstocks and continues to affect the scions even after they are inarched with good stocks. The next step in the experiment is thus to cut out the old variant stocks and leave the tops supported only by the good inarched stocks; but this has not yet been done.

Moreira (1938*a*, 1938*b*), in Brazil, found that the Barão sweet orange (Laranja Barão) grafted onto sweet lime (Lima da Pérsia) planted in 1930, gave very poor results: 56.9 per cent of the trees died within four years, though the symptoms of dieback, yellow leaves, and small, very acid fruits did not appear during the first three years. He stated that trees nearly dead were completely revived and returned to original vigor by inarching with seedling trees of sour orange (*Citrus Aurantium*) and thus bridging over the inhibiting effects of the original stock.

The rejuvenation or recovery, by inarching, of orchard trees supposed to be unsatisfactory or in decline because of uncongenial rootstocks is complicated and little understood. Usually, the cost of working over such trees is likely to be nearly as great as that of planting new trees. In view of the doubt that is likely to exist, it would seem wise to dig out the old trees and plant young trees of known good character.

The top-working of orchard trees that have inadvertently been propagated from unproductive or variable strains of standard varieties of oranges, lemons, or grapefruits, but that are known to be on good stocks, is a different problem. Where a block of trees is found to be unsatisfactory because of the type of fruit produced, both the stocks and the scions may usually be considered as healthy and normal in vigor, and change of variety by top-working is likely to prove satisfactory. However, where occasional trees become unproductive and begin to decline, only extended experiments will determine whether the difficulty is in the rootstock or in the scion, or both, and the best thing to do is to destroy such trees and plant good trees in their places.

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## Chapter III

# CHOICE OF ROOTSTOCKS

BY

LEON D. BATCHELOR and MARVIN B. ROUNDS

In the preceding chapter the characters and reactions of citrus rootstocks under varying conditions have been discussed in some detail. Data have also been given about the rootstocks now used in the most important citrus-producing sections of the world. The purpose of the present chapter is (1) to emphasize the importance of careful selection of rootstocks for different citrus varieties; (2) to direct attention to the difficulties commonly encountered in choosing desirable rootstocks, and the need of considering the results of carefully planned experiments, as well as the findings of practical local experience; and (3) to report the results of certain rootstock experiments conducted by the California Citrus Experiment Station.

## THE IMPORTANCE OF CHOOSING SUITABLE ROOTSTOCKS

As has been pointed out in chapter ii, it is probably just as important to use, carefully selected, superior stocks as it is to use selected, superior fruit varieties. The selection of improved fruit varieties has been in progress for centuries, but the choice of the best stocks cannot be considered as having received due attention prior to about a century ago. Although propagation by budding and grafting was understood centuries earlier, it was generally considered a curious phenomenon, and most commercial trees throughout the world were grown as seedlings.

It seems evident that the general use of grafted and budded citrus trees first became the accepted commercial policy primarily as a result of the spread of the foot-rot or gummosis disease in the mid-nineteenth century (from about 1832 to 1860). It was discovered in Europe that the sour orange was resistant to the disease and could be employed successfully as a rootstock for susceptible citrus varieties. Since then, much attention has been given to choice of the best rootstocks for the different varieties; but, for the most part, dependence has been placed on the results obtained in a given place with one stock, or with only two or three others for comparison. If a rootstock gave commercially successful results, it was generally considered satisfactory. The greater part of the evidence available in any locality, with reference to successful stocks, is based on the experience of orchardists, and often this is perhaps the most reliable information obtainable. It should be recognized, however, that such local experiences are sometimes inadequate, as they do not include trials with a sufficient number of different stocks to supply valid comparisons. This is the condition under which the industry is operating in practically every citrus-growing region.

As competition increases, and as populations extend and areas of production become more restricted, it will become increasingly necessary to use every

known means of insuring the greatest production at the least possible cost. It is certain that one of the most important factors in production is the use of the best available rootstocks.

## ROOTSTOCKS COMMONLY USED IN THE PAST

The rootstocks used in the different citrus-growing regions exhibit a wide range of diversity. Since the discovery of the resistance of the sour orange (*Citrus Aurantium*) to attacks of the dreaded gummosis disease, that species has been used as a rootstock in most of the Mediterranean countries of Europe. From the mid-nineteenth century to the present time (1946), it has been the dominant rootstock, or almost the only stock, employed for varieties of the sweet orange and of the lemon in the great citrus-producing sections of Italy and Spain. The discovery in Sicily, about 1923 (see Fawcett, 1936), of the serious mal secco disease, to which the sour orange is particularly susceptible, should discourage the use of this stock in areas where mal secco is found. No stock resistant to both mal secco and gummosis has yet been developed.

In the early period of citrus development in both Florida and California, sweet orange seedlings were the most commonly used rootstocks. In the decade between 1870 and 1880, the extension of commercial orange-growing in Florida led to the top-working of large areas of sour orange groves growing wild in that state. (See Vol. I, pp. 28–31.) The success of these top-worked groves, which were all on comparatively low, rich hammock lands, directed attention to the sour orange as a successful stock for sweet orange varieties. Later, when gummosis became prevalent in sweet orange seedling orchards and the resistance of the sour orange was learned through the experience of growers in Mediterranean countries, the sour orange was adopted generally as the principal rootstock. For some time it was widely used in the propagation of the sweet orange, mandarin orange, grapefruit, and lemon. Later experience in Florida indicated that the sour orange was not satisfactory on the light sandy soils of certain of the high pine lands, or in the shallow soils of the southeastern coastal section, and it was largely superseded in these sections by the Rough lemon stock.

The Cleopatra mandarin, the grapefruit, and the trifoliate orange have also been used to some extent as rootstocks in Florida, but, though favored by some growers, they are not very generally employed.

In California, when budded trees were first employed instead of seedling trees, sweet orange seedlings were commonly used as rootstocks. Between 1890 and 1900, however, the sour orange to some degree superseded the sweet orange as a rootstock. After that time, for possibly two decades, many of the orchards planted were on sour orange stocks. Since 1920 the tendency has been somewhat away from the sour orange and toward the sweet orange as a rootstock for lemons and, to a degree, for oranges. The sour orange rootstock continues in general use for grapefruit orchards, however.

In South Africa, when the culture of seedlings was discontinued because of extensive damage by foot rot, the sour orange was used extensively as a stock. It proved entirely unsatisfactory (see p. 119) and was superseded

by the Rough lemon, which remains almost the only rootstock used in that country (Webber, 1925; Powell, 1930; Marloth, 1938).

In Australia, also, the Rough lemon is perhaps the most generally used rootstock, though sour, sweet, and trifoliate orange are also employed. In Palestine the rootstock most commonly used is the Palestine sweet lime, but because troublesome diseases attack it, growers seem inclined to favor sour orange or some other stock. In Japan, where the Satsuma is the principal orange grown commercially, the stock usually employed is the trifoliate orange, though the yuzu orange and certain other types are also used. In all countries various other stocks are used more or less, but in this limited discussion only those most commonly employed throughout the world in commercial citrus propagation are indicated. (For more detailed data see chap. ii.)

It should be noted that with Rough lemon, Palestine sweet lime, Cleopatra mandarin, or yuzu orange as a rootstock a definite variety is concerned, which is likely to give similar reactious wherever used. When sweet orange, sour orange, or grapefruit are named as the rootstock, however, there is no indication of the type or variety used. There are many and widely different types of each of these species, which are certainly of different genetic constitution and would probably give different reactions. In general, however, if seed for rootstock is taken from normal, vigorous trees of the species of sweet orange, sour orange, or grapefruit, the reactions of stock and scion in different combinations and in different locations are likely to be similar. In the rootstock investigations of the future, careful attention should be given to the choice of superior rootstock strains or varieties of each of these species, which will be best adapted to the conditions of the citrus districts where they are to be grown (see p. 174).

## FACTORS INVOLVED IN CHOOSING ROOTSTOCKS

The influence of the rootstock on the various characters of the scion or fruit variety is discussed rather fully in the preceding chapter and need not be repeated here. In the choice of a rootstock for any citrus variety, the most important characters to be considered are: (1) yield per tree or, more important, per acre; (2) quality, grade, and size of fruit produced, if affected by the rootstock; and (3) the probable length of the productive life of the tree.

These three important factors indicate the various complex conditions upon which the success of the orchard depends. The practical grower cares little about his orchard as a show place; his chief concern is the return per acre from the sale of the crop over a long series of years. Thorough congeniality of the stock with the scion variety may be desirable in order to achieve the best results; but, practically, the stock which produces the best yields of the best fruit over the lougest period is the best stock to use, whether or not it exhibits some slight overgrowth or undergrowth with the scion variety with which it is combined.

Soil adaptability is very important, because, though the principal stocks have a wide range of adaptability, each commonly gives superior results only on certain soil types, and the stock that is chosen should be known to give

the best results on the particular soil to be planted. Sour orange stock usually gives good results with most orange varieties in certain districts of Florida, on deep, rich, moist soils, but is commonly less successful on light sandy or shallow soils. Rough lemon, on the contrary, usually has given better results on sandy or gravelly loam soils which are especially well drained.

Sour orange rootstocks should be avoided in California for use on poorly drained soils. Underlying water tables in semiarid regions such as California usually contain harmful amounts of salts in solution. The relative amount of salt in such water has been generally observed to be several times as much as that in irrigation water used on these lands (Thomas, 1936), possibly even twenty times as much, depending on various conditions. In lemon orchards in Ventura County the ground water contained five to fifteen times as much total soluble salts as the water used for irrigation in the respective orchards. At times this ground water is only five to six feet from the surface and is thus available to a deep-growing rootstock such as sour orange. Under such conditions the sweet orange rootstock has proved much superior to the sour orange, apparently because the shallow-growing sweet orange takes in less water by subirrigation from such a salty water table. The sour orange has been unsatisfactory as a rootstock for lemon trees grown on clay loam soils, which are very retentive of moisture even though not actually underlain by a water table. Deterioration of such orchards has been especially bad in years of abnormally heavy rainfall (Jensen, Wilcox, and Foot, 1927).

The degree of resistance of a rootstock to a certain root and trunk disease, such as gummosis or orange-tree quick decline, may be of great importance. The presence of the disease may be a limiting element to successful crop production.

The influence of rootstocks on resistance of the trees to cold is of minor importance in California, because so many of the orchards in cold locations are heated during periods of extremely cold weather. The rootstocks do affect the hardiness of scions or tops of trees, however (see chap. ii, p. 94). Trees growing on sour orange rootstocks are, for example, more hardy than those growing on either sweet orange or Rough lemon. This is illustrated by a comparison of the two nine-year-old Marsh grapefruit trees, one on sour orange and the other on Rough lemon rootstock, shown in figure 70. These pictures were taken in the California rootstock plots two months after the trees had been subjected to a minimum temperature of 17° F. These trees were typical of those on the respective rootstocks after the freeze of January, 1937. In some citrus regions tender stocks may be effectively protected by banking with earth. This is done when a degree of cold is expected which would probably kill the entire tree. Especially tender trees, such as citron, common lime, or lemon, should never be planted except in warm or protected locations (see chap. iv, p. 224).

Finding the best possible rootstock for each fruit variety in every location is so difficult as almost to defy accomplishment. There are so many fruit varieties, each with its particular responses, so many varying conditions of soil and climate, so many possible rootstocks available for trial, and the tests

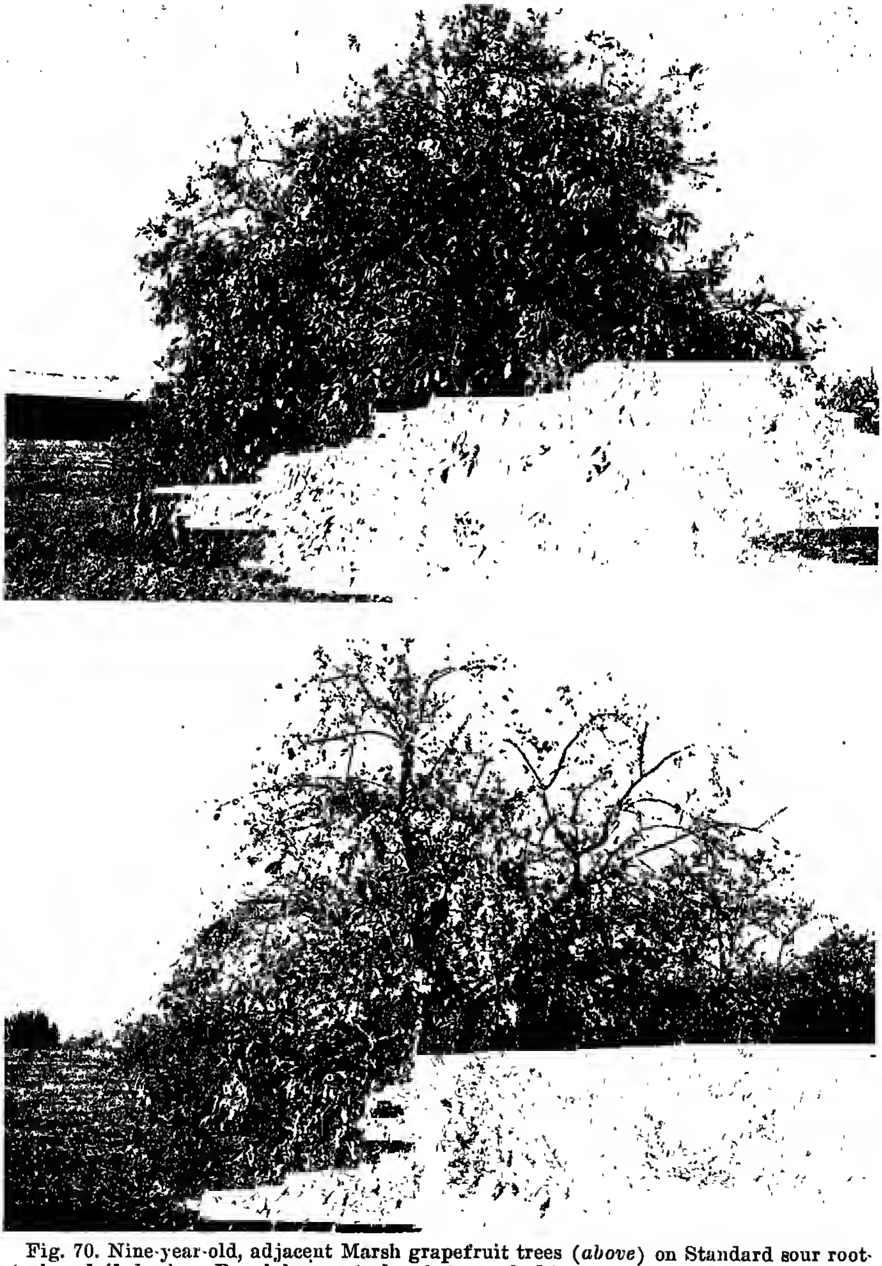

Fig. 70. Nine-year-old, adjacent Marsh grapefruit trees (*above*) on Standard sour rootstock and (*below*) on Rough lemon stock; photographed two months after being subjected to a temperature of 17° F., and showing the greater hardiness of the tree on the sour stock.

must be continued so long and on so large a scale, if in numbers to assure reliability, that the problem is nearly impossible of solution.

Most of the rootstocks now used in each citrus-growing area have been chosen after long years of experience. They do not usually represent a choice based on carefully planned comparative experiments; but many changes and eliminations have been made, and wide experience in culture is of the highest importance. A rootstock, however successful or promising in one area, should not be generally adopted in another area until its value there has been demonstrated by experience. A fertilizer formula or a spray method may be changed each year, but the rootstock cannot be changed without serious loss.

The size of the trees produced by a certain stock is, within certain limits, of minor importance, as the trees can be planted closer together if the stock produces a known degree of dwarfness. On some stocks, trees grow too large as old mature trees.

The importance of comparative experimental tests in the choice of rootstocks must be emphasized here. Choice has, in the past, been based on very meager evidence with respect to comparative yields of really comparable trees. Such data, to be reliable, require careful planning and years of observation. Nevertheless, it is on such experimental data, finally acquired in each general citrus-growing area, that the choice of stocks must be based. Many small and limited experiments have been made in many places, and some of these will be outlined here. The authors judge, however, that more will be gained by presenting a somewhat detailed report on the results of one such experiment than by attempting to outline the results of all the experiments.

## THE CALIFORNIA ROOTSTOCK EXPERIMENTS

Probably the most comprehensive and reliable data at present available on rootstock experiments in any area are those provided by experiments conducted by the California Citrus Experiment Station.[1] Little has been published concerning these experiments for fear that early results might be misleading—as has sometimes happened. A few preliminary reports have been published elsewhere (Webber, 1934*a*, 1934*b*, 1935; Batchelor and Webber, 1939; Batchelor and Rounds, 1944).

These experiments, which, for brevity's sake, are referred to in the text as the "California rootstock experiments," or merely as the "California experiments," included approximately 6,500 trees in the first planting. The number of trees has been much reduced, however, by discarding from time to time such stock varieties as were shown by their performance to be commercially worthless.

*Plan of experiments.*—The nursery stock used in these experiments was grown especially for the purpose, to assure certainty of the genetic type and the age of both stocks and scions. All trees of all combinations received the same care and treatment.

[1] The rootstock experiments of the California Citrus Experiment Station, discussed here, were organized and conducted by Dr. H. J. Webber from their beginning, in 1922, until 1936, when he retired from active service. Since that time they have been under the supervision of the senior author of this chapter.

The varieties chosen for comparative trial as rootstocks included several selections each of sweet orange, sour orange, mandarin orange, and grapefruit. Since little was known about the performance of the varieties as rootstocks, those included in the experiments were chosen mainly on the basis of the vigor and apparent healthiness of trees growing in the variety orchards of the California Citrus Experiment Station. Several selections, such as the Oroville and Bessie sweet oranges and the Duncan grapefruit, were made because of the great age and size of the parent seedling trees of the varieties. Several varieties of citranges (hybrids of trifoliate orange with the sweet orange) and the Sampson tangelo (hybrid of tangerine with grapefruit) were included because of the vigorous growth of the parent trees and the uniformity of their seedlings (see chap. ii, pp. 127–132). Other interesting species and varieties were also included, such as the Rough lemon, the trifoliate orange, the Calamondin orange, and certain intrageneric and intergeneric hybrids. (Descriptions of the varieties tested are, with few exceptions, given in Vol. I, chap. v.)

The seeds of each stock variety used for the seedling rootstocks were taken from a single selected tree of the variety. In many species and varieties of citrus, in which a high proportion of the seedlings develop from nucellar embryos, it is possible, by eliminating the variants among the seedlings, to obtain a progeny which are likely to be genetically identical individuals (see chap. ii, pp. 139–148). The seedlings of each stock variety were therefore carefully examined before they were budded, and all recognizable variants were discarded. It is thus reasonable to assume that the seedlings used were from nucellar embryos and represented approximately a genetically homogeneous progeny of each stock strain.

The scion varieties used in the experiments included Valencia and Washington Navel oranges, Eureka and Lisbon lemons, Marsh grapefruit, and Owari Satsuma. The buds for all trees of any one variety were taken from a single selected tree of that variety and were thus all of the same clonal strain. All trees of the Valencia orange used on the different stocks should thus be genetically identical, and the same should be true of the Eureka lemon or of any other variety used.

Each scion variety was tested on about thirty-five rootstocks. The tests were made in plots of five trees each, and were usually replicated two or three times in each orchard. Each variety, on all stocks, was usually grown in two different locations in southern California, under different climatic and soil conditions. The first field plantings were made in 1927 and were followed by additional annual plantings from 1928 to 1931.

The observations made and the notes taken on these experiments include annual yield per tree, size and condition of tree, and sometimes size and grade of fruit. Comparative size of tree is fairly well indicated by the area of a cross section of the trunk six inches above the bud union. Summaries of these measurements are used to indicate comparative tree size. Studies have shown that with citrus trees a high correlation exists between the area of trunk cross section and the top volume of the tree, the coefficient of correlation ranging from $+0.817 \pm 0.013$ to $+0.923 \pm 0.006$ (Webber, 1932*b*, p. 46).

### TABLE 11

EFFECT OF ROOTSTOCK ON SIZE AND YIELD OF VALENCIA ORANGE TREES, RIVERSIDE AND TUSTIN, CALIFORNIA

Orchards planted in 1927

| Rootstock species and variety | Riverside | | | | | Tustin | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number of trees[a] | Average size of trees[b] in 1939 (sq. cm.) | Average annual yield per tree (pounds) | | | Number of trees[a] | Average size of trees[b] in 1939 (sq. cm.) | Average annual yield per tree (pounds) | | |
| | | | 1931–1035 | 1936–1940 | 1931–1940 | | | 1931–1935 | 1936–1940 | 1931–1940 |
| Sweet orange: | | | | | | | | | | |
| Koethen | 10 | 258 | 106 | 213 | 159 | 10 | 315 | 187 | 231 | 209 |
| C.E.S. seedling 362 | 10 | 247 | 94 | 101 | 142 | 10 | 275 | 169 | 204 | 186 |
| Average | | 253 | 100 | 202 | 151 | | 205 | 178 | 217 | 107 |
| Sour orange: | | | | | | | | | | |
| African | 10 | 209 | 84 | 167 | 125 | 10 | 258 | 145 | 215 | 180 |
| Brazilian | 15 | 197 | 100 | 184 | 142 | 34 | 242 | 160 | 236 | 108 |
| Rubidoux | 20 | 209 | 97 | 200 | 148 | 15 | 268 | 158 | 246 | 202 |
| Average | | 205 | 95 | 187 | 141 | | 251 | 157 | 235 | 196 |
| Mandarin: | | | | | | | | | | |
| Cleopatra | 15 | 243 | 87 | 177 | 132 | 15 | 262 | 140 | 197 | 168 |
| Grapefruit: | | | | | | | | | | |
| C.E.S. seedling 343 | 10 | 174 | 62 | 151 | 106 | 10 | 230 | 151 | 107 | 174 |
| Duncan | 10 | 241 | 73 | 143 | 108 | 5 | 261 | 139 | 185 | 162 |
| Average | | 207 | 67 | 147 | 107 | | 245 | 145 | 191 | 168 |
| Shaddock: | | | | | | | | | | |
| Siamese | 10 | 187 | 55 | 140 | 97 | 5 | 259 | 151 | 234 | 192 |
| Rough lemon | 15 | 234 | 103 | 173 | 138 | 15 | 242 | 194 | 192 | 193 |
| Sampson tangelo | 15 | 280 | 98 | 184 | 141 | 10 | 236 | 132 | 194 | 163 |

Orchards planted in 1928

| Rootstock species and variety | Riverside | | | | | Tustin | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number of trees[a] | Average size of trees[b] in 1939 (sq. cm.) | Average annual yield per tree (pounds) | | | Number of trees[a] | Average size of trees[b] in 1939 (sq. cm.) | Average annual yield per tree (pounds) | | |
| | | | 1932–1936 | 1937–1941 | 1932–1941 | | | 1932–1936 | 1937–1940 | 1932–1940 |
| Sweet orange: | | | | | | | | | | |
| Homosassa | 9 | 291 | 104 | 218 | 161 | 10 | 303 | 219 | 268 | 241 |
| Sour orange: | | | | | | | | | | |
| Standard | 14 | 203 | 92 | 190 | 141 | 10 | 222 | 158 | 212 | 182 |
| Mandarin: | | | | | | | | | | |
| Clementine | 10 | 213 | 97 | 192 | 144 | 10 | 257 | 170 | 246 | 204 |
| Cleopatra | 10 | 221 | 85 | 182 | 133 | 5 | 235 | 112 | 207 | 154 |
| Dancy | 10 | 214 | 100 | 172 | 136 | 10 | 244 | 157 | 242 | 195 |
| Average | | 216 | 94 | 182 | 138 | | 247 | 153 | 237 | 190 |
| Citrange: | | | | | | | | | | |
| Cunningham | 10 | 120 | 75 | 132 | 103 | 14 | 110 | 109 | 90 | 101 |
| Savage | 12 | 167 | 70 | 99 | 84 | 8 | 139 | 143 | 178 | 159 |
| Average | | 146 | 72 | 114 | 93 | | 120 | 121 | 122 | 122 |
| Trifoliate orange | 15 | 160 | 82 | 222 | 152 | 10 | 126 | 129 | 179 | 151 |
| Shaddock × St. Michael, hybrid | 13 | 198 | 94 | 210 | 152 | 12 | 224 | 178 | 240 | 206 |

TABLE 11—(*Continued*)

EFFECT OF ROOTSTOCK ON SIZE AND YIELD OF VALENCIA ORANGE TREES, RIVERSIDE AND TUSTIN, CALIFORNIA

Orchards planted in 1929

| Rootstock species and variety | Riverside | | | | | Tustin | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number of trees[a] | Average size of trees[b] in 1940 (sq. cm.) | Average annual yield per tree (pounds) | | | Number of trees[a] | Average size of trees[b] in 1940 (sq. cm.) | Average annual yield per tree (pounds) | | |
| | | | 1933–1937 | 1938–1942 | 1933–1942 | | | 1933–1937 | 1938–1940 | 1933–1940 |
| Oroville sweet | 10 | 288 | 84 | 176 | 130 | 14 | 266 | 194 | 217 | 203 |
| Sampson tangelo | 10 | 331 | 111 | 189 | 150 | 10 | 320 | 192 | 250 | 214 |
| Trifoliate orange | 10 | 174 | 84 | 211 | 147 | 15 | 130 | 124 | 155 | 136 |
| Sweet lemon: | | | | | | | | | | |
| Millsweet | 8 | 196 | 67 | 122 | 94 | 14 | 161 | 148 | 147 | 148 |

[a] At the end of the experiment.
[b] Comparative tree size indicated by area of cross section of trunk six inches above bud union.

## ROOTSTOCKS FOR VALENCIA ORANGE

The California rootstock experiments with Valencia orange, which are summarized here, were conducted in orchards that were approximately duplicates, one at Riverside, on Ramona loam soil, and the other at Tustin,[1] on soil classified as Yolo clay loam.

*Average size and yield of trees on different rootstocks.*—In table 11 the records of average tree size, as indicated by area of cross section of trunk, expressed in square centimeters, and the average annual yields are tabulated for the two experimental orchards. The yield records extend over a ten-year period, except for the two plantings at Tustin in 1928 and 1929, for which records for only nine and eight years, respectively, were available. It is evident from the data that the size of the trees and thus the bearing area of the tops were affected by the rootstocks.

The trees on sweet orange rootstocks (fig. 71) averaged approximately 25 to 30 per cent larger than those on sour orange rootstocks (fig. 72); the trees on mandarin orange roots were intermediate between those on sweet and sour orange, but are nearly as large as the sweet-stock trees at twenty years of age. Although the trees on grapefruit rootstocks were extremely variable, they averaged about the size of those on sour orange rootstock. The Sampson tangelo rootstock (see fig. 73) produced notably larger trees than the sweet orange, in three comparisons out of four. Valencia trees on trifoliate orange rootstock were approximately 60 per cent as large as those of the same variety on sweet orange rootstock, in the Riverside orchard (compare figs. 71 and 74). In the sandy loam soil at Riverside, the trifoliate rootstocks made a better relative growth than in the clay loam soil at Tustin. Although the Rough

[1] These localities differ considerably in their climatic conditions. (See Vol. I, on the coastal section, p. 73, and the interior valley section, p. 77.)

Fig. 71. Seventeen-year-old Valencia orange on Koethen sweet orange rootstock in the experimental plots at the Citrus Experiment Station, Riverside, California.

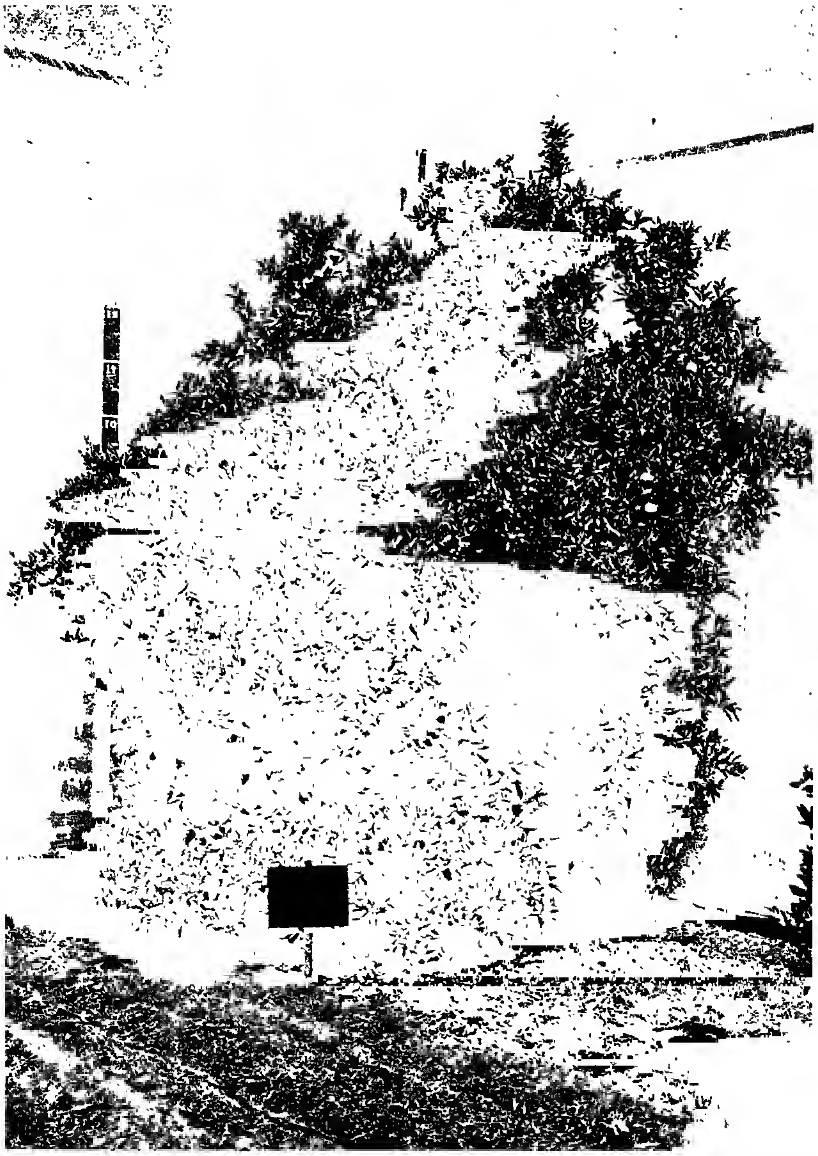

Fig. 72. Seventeen-year-old Valencia orange on Brazilian sour orange rootstock in experimental plots at the Citrus Experiment Station, Riverside, California.

Fig. 73. Seventeen-year-old Valencia orange tree on Sampson tangelo rootstock in experimental plots at the Citrus Experiment Station, Riverside, California.

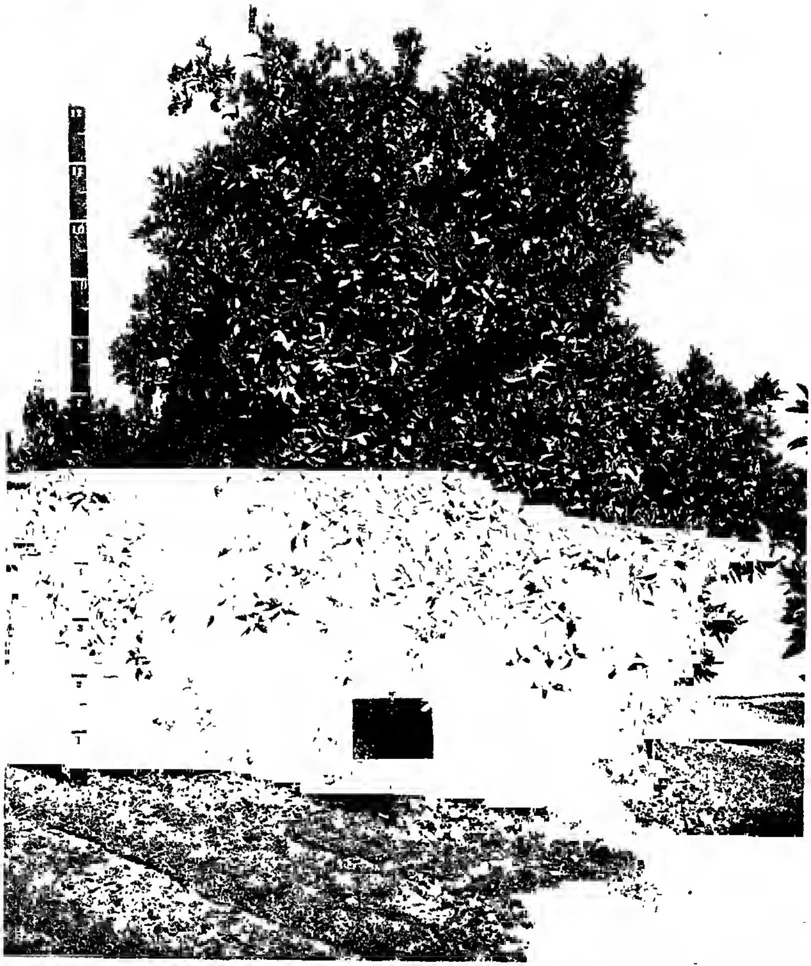

Fig. 74. Seventeen-year-old Valencia orange tree on trifoliate orange rootstock in experimental plots at the Citrus Experiment Station, Riverside, California.

lemon rootstock made a rapid-growing nursery tree, and a young orchard tree that was above average size, this superior growth characteristic was not sustained after a few years in the experimental orchards (see measurements recorded in table 11, pp. 176–177).

While the production of fruit on the Valencia trees on Rough lemon rootstock at Tustin averaged practically the same as that of the trees on sweet orange rootstock, the tops on Rough lemon stock were considerably smaller (compare figs. 75 and 76).

The extreme range in tree sizes caused by the rootstocks was less with Valencia orange than with either lemons or grapefruit (see p. 177). With the Marsh grapefruit, for example, the size ratio of the trees on sweet orange rootstock to those on trifoliate was 100:26, whereas the same comparison for Valencia orange was 100:55. The citrange rootstocks, however, dwarfed the Valencia orange slightly more than they did the Marsh grapefruit. Both times, the citrange rootstocks appeared to be better adapted to the loam soil at Riverside than to the clay soil at Tustin, as the trees were less dwarfed at Riverside. The size ratio of the Valencia orange trees on sweet orange stock to those on Cunningham citrange at Riverside was 100:41, and at Tustin, 100:36; the ratios to trees on Savage citrange in these same locations were 100:57 and 100:46, respectively. The general appearance of the Valencia trees on the citrange rootstocks was subnormal; the leaves were small and more mottled, and the density of the foliage was much less than on trees on sweet, sour, or trifoliate stocks.

It seems doubtful from these experiments whether the Cunningham or Savage citranges are sufficiently compatible with the Valencia orange to be worth even limited commercial trial; the possibility is not excluded, however, that other citranges may prove satisfactory. The same situation exists with respect to trees of these stocks budded to Washington Navel (see p. 191). This is in striking contrast to the trial of these citranges with Marsh grapefruit tops (see p. 204).

Valencia oranges are commonly propagated on sweet orange, sour orange, and Rough lemon rootstocks. The yield records in table 11 indicate that, generally, no significant difference in productiveness resulted from the use of these different rootstocks. The apparent exception is the Standard sour orange rootstock compared with the Homosassa sweet orange in the 1928 plantings. The Standard sour orange trees in the 1928 plantings have consistently produced less than the sweet, and have averaged 12 per cent less at Riverside and 24 per cent less at Tustin. The former difference, if taken alone, might not be considered significant, but, with a much greater difference in the same direction at Tustin, it is probable that for the Valencia orange the Standard sour orange is a relatively inferior stock in comparison with the Homosassa sweet orange. The trees on grapefruit rootstocks have consistently produced less fruit than those on sweet orange. At Riverside, the difference in yield was greater than the difference in tree size; at Tustin, the converse was true. The clay loam soil at Tustin is apparently better adapted to grapefruit rootstock than the much lighter soil in the Riverside orchard.

Fig. 75. Seventeen-year-old Valencia orange tree on Rough lemon rootstock in experimental plots at Tustin, California.

The mandarin orange rootstocks with the Valencia orange have consistently produced smaller trees and less fruit than the sweet orange. The same holds true in comparing the Valencia trees on the two citrange stocks with those on sweet orange rootstock. An exception to this general rule, that the smaller trees yield less, is seen in comparing the trees on sweet orange rootstock with

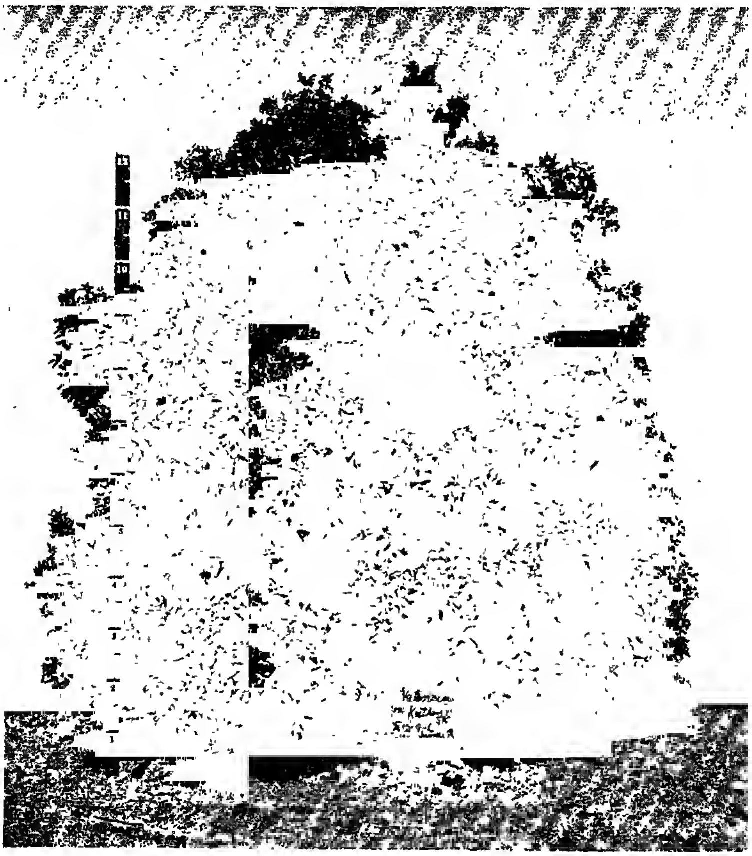

Fig. 76. Seventeen-year-old Valencia orange tree on Koethen sweet orange rootstock in experimental plots at Tustin, California.

those on trifoliate roots in the Riverside orchard, where the smaller trees on trifoliate roots have produced practically the same amount of fruit as the larger trees on sweet orange roots. At Tustin, however, the yield of the trees on sweet orange rootstock exceeded that of the trees on trifoliate by 50 to 60 per cent. Apparently, the light loam soil at Riverside is relatively better adapted to the trifoliate rootstock than the clay loam soil at Tustin.

One of the uncommonly used rootstocks, the Sampson tangelo, has proved to be adapted for use with the Valencia orange. In most comparisons the

Sampson tangelo trees produced nearly the same amount of fruit as the sweet orange rootstock trees of the same age.

The different varieties of sweet orange used for rootstocks in these experiments have produced nearly the same results, with the exception of the Oroville sweet orange at Riverside, where it appears less desirable than other sweet stocks. The different varieties of sour orange rootstock show greater variation, and it is very probable that the African sour is inherently inferior to the Brazilian or Rubidoux sour orange for use with Valencia orange. The differences between these varieties of sour orange were small in the Marsh grapefruit and Washington Navel orange experiments (see p. 191), where the production ranged from 11 to 32 per cent, respectively. Inasmuch as they were all in the same direction, in ten comparisons, it is exceedingly improbable that these small differences could have been due to chance. We therefore consider the African sour orange, as compared with other sour orange varieties, an undesirable rootstock for Valencia orange.

A selection among the varieties of grapefruit and mandarin oranges used as rootstocks seems less certain. There were probably too few trees, and the differences were too small, to give one assurance that among the few varieties used any were significantly superior or inferior to the others. The two citranges as rootstocks have been discussed above. It is interesting to note that although the Cunningham dwarfed the Valencia orange top more than the Savage at both Riverside and Tustin, it nevertheless produced more fruit than the Savage at Riverside.

The quality of Valencia oranges as affected by the rootstocks has been studied over a series of years by Sinclair and Bartholomew (1944), to whom we are indebted for figure 77. This graph shows the relative concentrations of certain soluble organic constituents in the juice of mature fruits from both experimental orchards, averaged for a three-year period. Some of the differences shown in this chart are doubtless due to chance variations in random samples, but considering the number of trees sampled, and the fact that observations were carried on over three years, there are nevertheless some small but consistent differences in fruit quality which are apparently due to the rootstocks. Rough lemon and Siamese shaddock rootstocks are associated with low-quality fruit because of the subnormal amount of acid, total sugars, and total solids in fruits on these stocks. Even with a high ratio of soluble solids to acid, the fruit would be considered relatively flat in flavor. This contrast is especially noteworthy in comparing the fruit from Rough lemon and from Sampson tangelo trees. Oranges from the latter are higher in both total soluble solids and acids, and the fruit thus has a more positive flavor. (For a detailed discussion of these differences see Sinclair and Bartholomew, 1944.) It is of added interest to note that the Valencias from the warmer zone at Riverside were consistently higher in total soluble solids than those on the same rootstocks from the coastal district at Tustin. The fruit from the coastal district was smoother and more nearly spherical than that from Riverside (see fig. 78). The fruit from Riverside had a perceptibly more sprightly flavor, however, than that from near the coast.

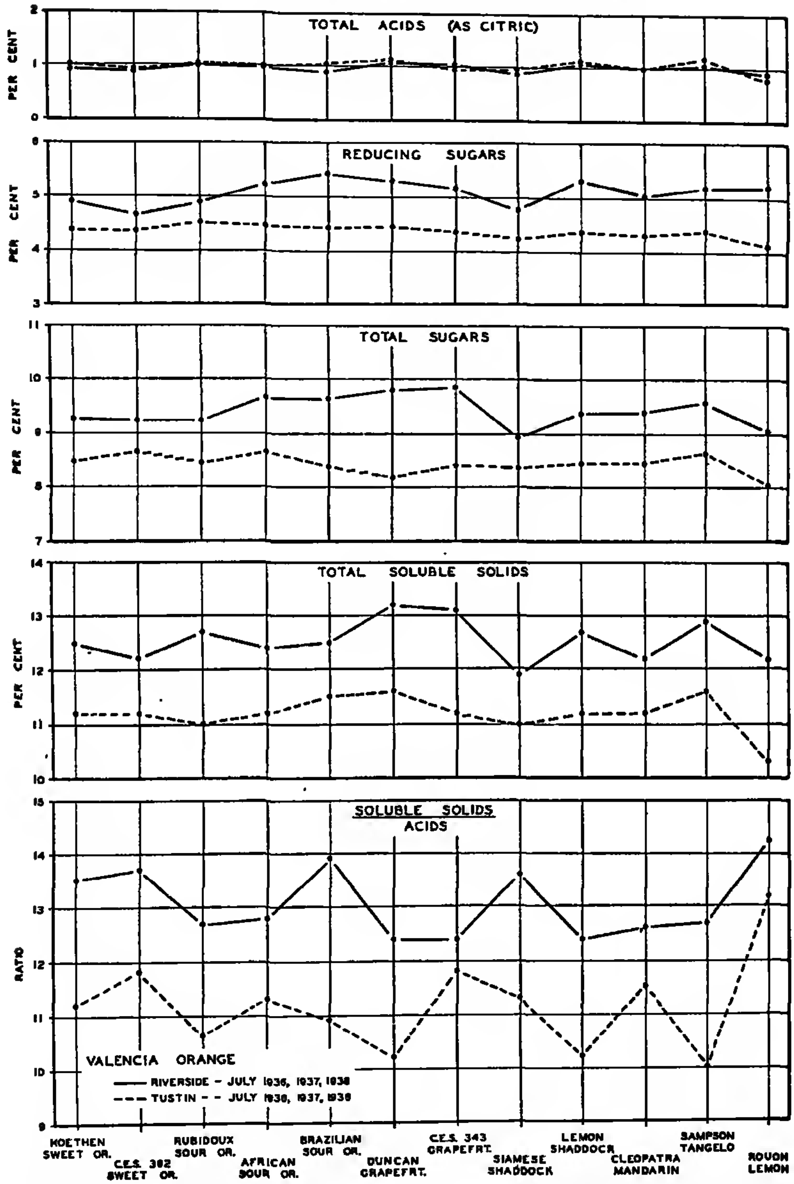


Fig. 77. Relative concentrations of certain soluble organic constituents in the juice of mature fruits from Valencia orange trees budded on different stocks and grown in plots at Riverside and Tustin. Fruit samples were taken from both locations in July, in three consecutive years. The value recorded for each stock is the mean value for the three years. (From Sinclair and Bartholomew, 1944, p. 136.)

*Conclusions.*—The information obtained from these experiments indicates that there is not enough difference in the yields of trees on sweet and sour orange rootstocks, either at Riverside or at Tustin, to predicate exclusively on a basis of yield the use of these rootstocks for Valencias. The selection of the stock, as between these two varieties, should probably be decided on the basis of other considerations, such as relation to disease susceptibility. Sour orange, for example, is much more resistant than sweet orange to fungus dis-

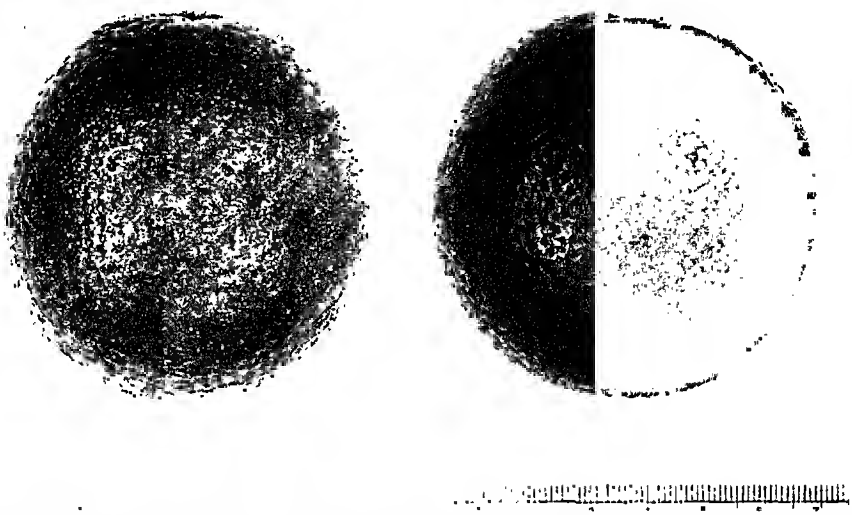

**Fig. 78. Valencia oranges produced on the same rootstock but in different locations. The more elongated fruit on the left was grown in the warmer, inland district, at Riverside; the smoother-skinned, more nearly spherical fruit on the right was grown in the coastal district, at Tustin.**

eases such as brown-rot gummosis. Orange trees propagated on sour orange rootstocks are, however, subject to tristeza (Webber, 1943) and orange-tree quick decline (Fawcett and Wallace, 1946). (See chap. xi, below.)

Valencia trees on sweet orange and on Sampson tangelo are somewhat larger than those on sour orange, and a smaller number of trees per acre might therefore be desirable in a commercial orchard. The mandarin orange as a rootstock usually produces trees intermediate in size between those on sweet orange and on sour orange. Trees on mandarin stock sometimes exceed those on sour stock in production; they are also more resistant to brown-rot gummosis than trees on sweet orange rootstocks.

Valencias on Rough lemon equal those on sweet and sour orange in amount of yield, but fruit produced by trees budded on Rough lemon is inferior in quality to that of most other rootstocks.

## ROOTSTOCKS FOR WASHINGTON NAVEL ORANGE

The rootstock experiments with the Washington Navel orange which are summarized here were conducted in the experimental orchards of the California Citrus Experiment Station at Riverside, on Ramona loam soil.

*Average size and yield of trees on different rootstocks.*—Average tree size and average annual yield of Washington Navel orange trees on different rootstocks are recorded in table 12. Plantings were made on adjacent areas in

TABLE 12

EFFECT OF ROOTSTOCK ON SIZE AND YIELD OF WASHINGTON NAVEL ORANGE TREES, RIVERSIDE, CALIFORNIA

Orchard planted in 1927

| Rootstock species and variety | Number of trees[a] | Average size of trees[b] in 1939 (sq. cm.) | Average annual yield per tree (pounds) | | | |
|---|---|---|---|---|---|---|
| | | | 1931–1935 | 1936–1940 | 1941–1943 | 1931–1943 |
| Sweet orange: | | | | | | |
| Average of three varieties | 15 | 199 | 66 | 151 | 112 | 109 |
| Sour orange: | | | | | | |
| African | 9 | 161 | 60 | 161 | 127 | 116 |
| Brazilian | 23 | 181 | 79 | 213 | 173 | 152 |
| Rubidoux | 15 | 166 | 84 | 202 | 174 | 153 |
| Average | | 171 | 77 | 200 | 165 | 145 |
| Mandarin: | | | | | | |
| Cleopatra | 10 | 200 | 73 | 127 | 96 | 99 |
| King | 10 | 202 | 77 | 149 | 85 | 106 |
| Oneco | 10 | 164 | 54 | 129 | 79 | 88 |
| Average | | 189 | 68 | 135 | 87 | 98 |
| Grapefruit: | | | | | | |
| C.E.S. seedling 343 | 10 | 136 | 47 | 116 | 61 | 77 |
| Duncan | 9 | 195 | 53 | 112 | 56 | 76 |
| Average | | 164 | 50 | 114 | 59 | 77 |
| Shaddock: | | | | | | |
| Siamese | 10 | 136 | 46 | 110 | 75 | 77 |
| Rough lemon | 15 | 162 | 90 | 195 | 152 | 145 |
| Sampson tangelo | 10 | 212 | 88 | 143 | 66 | 104 |

Orchard planted in 1928

| Rootstock species and variety | Number of trees[a] | Average size of trees[b] in 1939 (sq. cm.) | Average annual yield per tree (pounds) | | | |
|---|---|---|---|---|---|---|
| | | | 1932–1936 | 1937–1941 | 1942–1943 | 1932–1943 |
| Sweet orange: | | | | | | |
| C.E.S. seedling 362 | 10 | 196 | 96 | 183 | 89 | 131 |
| Mandarin: | | | | | | |
| Clementine | 10 | 198 | 56 | 153 | 71 | 99 |
| Citrange:[c] | | | | | | |
| Morton | 5 | 168 | 133 | 300 | 188 | 212 |
| Cunningham | 14 | 92 | 59 | 104 | 45 | 75 |
| Savage | 24 | 125 | 40 | 78 | 49 | 57 |
| Average | | 119 | 57 | 115 | 64 | 81 |
| Trifoliate orange | 10 | 115 | 59 | 204 | 157 | 136 |

TABLE 12—(*Continued*)

EFFECT OF ROOTSTOCK ON SIZE AND YIELD OF WASHINGTON NAVEL ORANGE TREES, RIVERSIDE, CALIFORNIA

Orchard planted in 1929

| Rootstock species and variety | Number of trees[a] | Average size of trees[b] in 1940 (sq. cm.) | Average annual yield per tree (pounds) | | | |
|---|---|---|---|---|---|---|
| | | | 1933–1937 | 1938–1942 | 1943 | 1933–1943 |
| Sweet orange: | | | | | | |
| Oroville | 10 | 208 | 81 | 165 | 48 | 116 |
| Sour orange: | | | | | | |
| Standard | 15 | 157 | 55 | 180 | 65 | 113 |
| Mandarin: | | | | | | |
| Cleopatra | 10 | 210 | 54 | 170 | 33 | 105 |
| Sampson tangelo | 10 | 225 | 54 | 163 | 41 | 102 |
| Trifoliate orange | 15 | 127 | 62 | 209 | 102 | 132 |

Orchard planted in 1930

| Rootstock species and variety | Number of trees[a] | Average size of trees[b] in 1939 (sq. cm.) | Average annual yield per tree (pounds) | | | |
|---|---|---|---|---|---|---|
| | | | 1934–1938 | 1939–1943 | | 1934–1943 |
| Sweet orange: | | | | | | |
| C.E.S. seedling 358 | 19 | 159 | 80 | 189 | ... | 134 |
| Sour orange: | | | | | | |
| Bittersweet | 15 | 117 | 64 | 198 | .. | 131 |
| Rough lemon | 10 | 147 | 105 | 195 | ... | 150 |
| Citrange: | | | | | | |
| Morton | 20 | 137 | 128 | 252 | ... | 190 |

[a] At the end of the experiment.
[b] Comparative tree size indicated by area of cross section of trunk six inches above bud union.
[c] Of trees on Coleman citrange rootstock, 80 per cent died; no data reported.

1927, 1928, 1929, and 1930. All yield comparisons extended over a period of ten years or more.

The rootstocks have had a striking effect on the size and health of the trees, and thus on bearing area and production. The trees on sweet orange rootstock were somewhat larger than those on sour orange, as judged by the average size of all the sweet orange rootstock trees planted in 1927 compared with that of all the sour orange rootstock trees planted the same year, the size ratio of sweet orange trees to sour being 100:86. When trees on sweet orange rootstocks were compared with those on trifoliate in the same planting, the size ratio of sweet to trifoliate was approximately 100:60.

The Cunningham citrange rootstock dwarfed the Navel trees more than the trifoliate stock did. Some of this excessive dwarfing was probably due to extreme incompatibility between the Cunningham and the Navel, for the orange trees on this rootstock were subnormal in general health and appearance as well as dwarfed in size. The trees on mandarin orange rootstock were approximately the same size as those on sweet orange; the trees on Rough

lemon, like those on sour orange rootstock, were somewhat smaller. The trees on grapefruit rootstock averaged smaller and were more variable in size than those on any other citrus species used.

Washington Navel orange trees are commonly propagated on sweet orange, sour orange, and Rough lemon rootstocks. The yield differences in table 12 show that for the thirteen-year average in the 1927 planting the sour orange was 33 per cent more productive than the sweet orange. The mandarin orange rootstocks averaged 11 per cent less than the sweet orange rootstocks, and the grapefruit stocks 29 per cent less. The general impression of trees on grapefruit rootstocks is that they are extraordinarily unproductive, considering their size and appearance. Trees on the Sampson tangelo rootstock averaged somewhat less fruit than those on the sweet orange rootstock, over the entire period, in the two orchards of the 1927 and 1929 plantings. In the 1927 planting, in the last three years (1941 to 1943, inclusive), the trees on Sampson tangelo had more mottle-leaf than those on sweet orange and were clearly inferior to the latter in production. The trees on Sampson tangelo have generally been less productive than those on sour orange, even though the former are considerably larger. This hybrid rootstock is of less promise for commercial use with Washington Navel orange than with Valencia. Further studies may show that trees on Sampson tangelo rootstocks have nutritional requirements differing from those of other rootstocks.

The trees on trifoliate rootstock have grown more slowly than those on sweet orange roots. The average yields for the eleven-year period were practically equal, however, on these two rootstocks in the 1928 plantings. In both the 1928 and the 1929 plantings, the yields in 1942 and 1943 showed a greater difference in favor of the trifoliate rootstock trees than theretofore. In the orchard planted in 1928, the yields of the trees on trifoliate rootstock were 87 per cent greater than those on sweet orange in 1942, and 66 per cent greater in 1943. In the orchard planted in 1929, the production of the trifoliate trees exceeded that of the sweet rootstock trees by 125 per cent in 1942, and by 112 per cent in 1943. Both years were somewhat unfavorable for the production of Navel oranges in various experimental orchards in adjacent fields. Whatever the cause of this intangible adversity, the trees on trifoliate rootstock were less seriously affected than those on sweet rootstock.

The annual production of the trifoliate trees, for the years 1939 to 1943, inclusive, exceeded that of the comparable sweet orange trees in each of the experimental orchards. The following tabulation shows these comparisons on an annual basis.

| *Date of planting, and roostock variety* | *Average yield per tree (pounds)* | | | | | |
|---|---|---|---|---|---|---|
| 1928 | 1938 | 1939 | 1940 | 1941 | 1942 | 1943 |
| Sweet orange seedling 362 | 186 | 240 | 221 | 146 | 89 | 90 |
| Trifoliate | 134 | 258 | 307 | 238 | 166 | 149 |
| 1929 | | | | | | |
| Oroville sweet orange seedling | 150 | 213 | 219 | 177 | 64 | 48 |
| Trifoliate | 129 | 228 | 293 | 249 | 144 | 102 |

The four citrange rootstocks used are especially interesting because of the extremely divergent results obtained from the respective varieties, which originated from a single hybridized fruit (see citranges, Vol. I, p. 654). The Coleman citrange was a complete failure. It had a dwarfing effect on the trees, half of which died before they were ten years old. The Cunningham citrange also dwarfed the trees to less than half the size of the trees on the sweet orange rootstock, with yields in somewhat the same proportion. The trees on Cunningham citrange stock were subnormal in general health and were affected more by zinc deficiency than trees on sweet orange root; they may be considered a practical failure in the experimental orchard. The dwarfing effect of the Savage citrange was less extreme than that of the Cunningham, as may be seen by a comparison of the trees in figure 79; but the foliage was subnormal in size and density, the amount of dead twigs in the trees was excessive, and zinc-deficiency symptoms were more apparent than in the sweet orange rootstock trees. The Savage citrange should be considered a failure in this orchard. The Morton citrange, on the other hand, has produced trees nearly as large as those on the sweet orange, as may be noted by comparing figures 80 and 81, and has been notably and consistently more productive. The Morton citrange trees have shown some overgrowth of the rootstock, as compared to the scion, but to a less degree than trees on trifoliate root. The trees are normal and healthy in appearance, however, and have a tendency to grow somewhat more upright than those on sweet orange rootstock.

The consistently greater average production of Washington Navel trees on Morton citrange than on any other comparable rootstock suggests that this citrange merits further experimentation. The orchard planted in 1930 is the only one having a sufficient number of trees on this stock for a reliable comparison with sweet orange rootstock. In this orchard the trees on Morton citrange have exceeded those on sweet orange in yield every year out of ten, and have exceeded the trees on Rough lemon roots eight years out of ten. The average yield for the first five years was 60 per cent more than that of the sweet stock, and 22 per cent more than that of the Rough lemon. On a ten-year basis, the yield of the Morton citrange trees has exceeded that of the sweet orange rootstock trees by 42 per cent, and that of the Rough lemon by 27 per cent. The Morton citrange would merit commercial trial as a rootstock for Washington Navel oranges if a practical way could be found of obtaining the Morton seedling trees in quantity for nursery purposes. The fruit of the Morton citrange is nearly seedless, and its use as a rootstock will probably be impracticable unless this peculiarity can be overcome.

Among the sour orange varieties, the African is significantly inferior to Brazilian or Rubidoux, as judged by the yields of Washington Navel trees on these rootstocks (see also Valencia, p. 185, and Marsh grapefruit, p. 209).

The mandarin orange varieties, as rootstocks for the Washington Navel orange, are variable in production and compatibility. The same may be said of the different varieties of grapefruit tested. As a group, the grapefruits are the least desirable of any citrus species used as rootstocks in this experiment, under the existing conditions.

Fig. 79. Eleven-year-old Washington Navel orange trees of the 1928 planting at the Citrus Experiment Station, Riverside, California: (*left*) on Savage citrange rootstock, and (*right*) on Cunningham citrange rootstock.

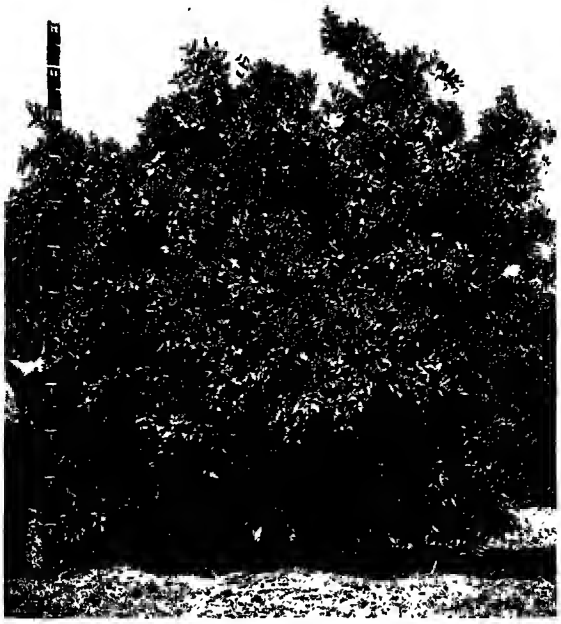

Fig. 80. Eleven-year-old Washington Navel orange tree on rootstock of sweet orange seedling 358, in the 1930 planting at the Citrus Experiment Station, Riverside, California.

The quality of Washington Navel orange fruit as affected by the rootstocks has been the subject of studies by Sinclair and Bartholomew (1944), to whom we are indebted for figure 82. The graphs show the total soluble organic solids in the juice of mature Washington Navel fruit from trees on different rootstocks; also the reducing sugars, total sugars, and total acids (as citric). There is apparently a noticeable casual variation between fruit samples from trees on different species of citrus and on different varieties within a given species.

Fig. 81. Eleven-year-old Washington Navel orange tree on Morton citrange rootstock, in the 1930 planting at the Citrus Experiment Station, Riverside, California.

The Savage citrange, the Duncan grapefruit, and the Sampson tangelo rootstocks all produced fruit relatively high in total soluble solids. The fruit from the tangelo trees was also high in acid, as in the Valencia trials (see p. 185). The Navel oranges produced on the Rough lemon rootstocks were low in total soluble solids, and in acids also, and would thus be considered by many persons to have lower-quality fruit than that produced on most of the other rootstocks. This is consistent with the low total of soluble solids in fruit of Marsh grapefruit and of Valencia orange produced on Rough lemon rootstocks. The Washington Navel oranges on the trifoliate rootstocks were also significantly lower in total soluble solids than those on most of the other stocks.

*Conclusions.*—The sour orange, sweet orange, and Rough lemon have all

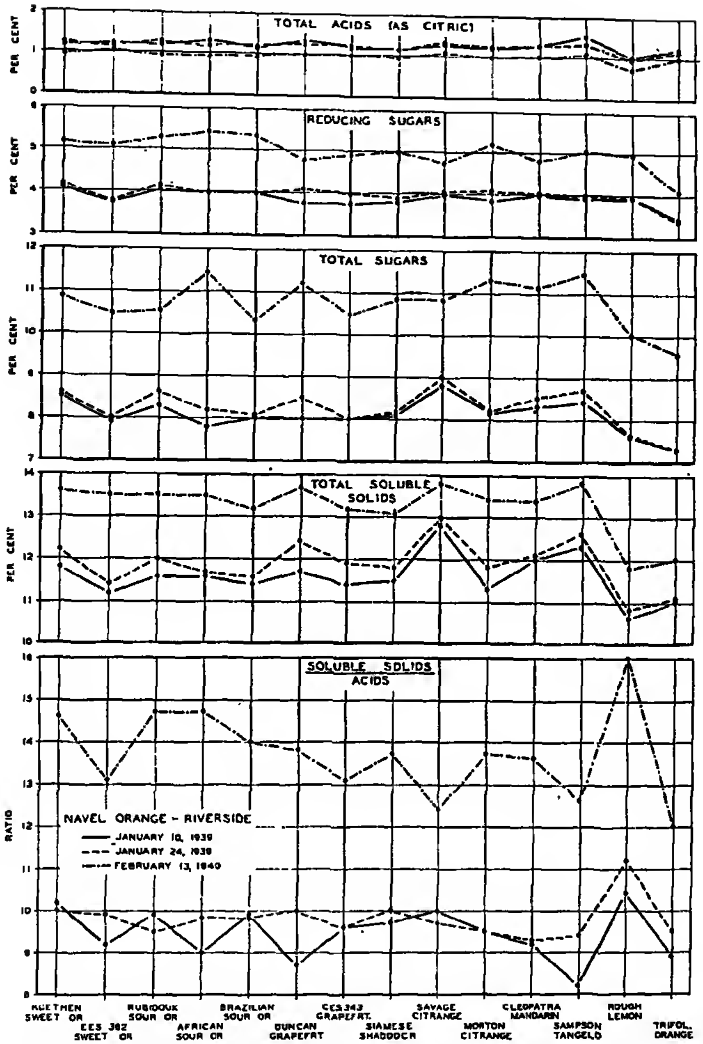


Fig. 82. Relative concentrations of certain soluble organic constituents in the juice of mature fruits from Washington Navel orange trees budded on different stocks and grown in plots at Riverside. Values recorded are those of two fruit samples gathered in January, 1939, and one sample gathered in February, 1940. (From Sinclair and Bartholomew, 1944, p. 140.)

produced satisfactory trees when used as rootstocks for the Washington Navel orange variety. The yields with these three rootstocks have not varied greatly or consistently. The fruit from the Rough lemon rootstock trees is not so high in quality, however, as that from either sweet or sour orange trees.

Because of the low quality of the fruit, Rough lemon stock probably should not be used even in an open-type soil such as a gravelly or sandy loam.

Sour orange stock is less susceptible to brown-rot gummosis than either sweet orange or Rough lemon. Since trees on sour orange rootstock are smaller than those on sweet orange, more trees can be planted per acre.

If trifoliate orange rootstock is used, more trees should be planted per acre than with either sweet or sour orange stocks, as the trees are consistently smaller than on those rootstocks.

The Morton citrange would be a promising rootstock for the Washington Navel if practical means could be found to produce seedy Morton fruit for nursery use.

## ROOTSTOCKS FOR OWARI SATSUMA ORANGE

The rootstock experiments with the Satsuma orange which are summarized here were conducted in the experimental orchards of the California Citrus Experiment Station at Riverside, on Ramona loam soil.

*Average size and yield of trees on different rootstocks.*—In table 13, average tree sizes and average annual yields of Owari Satsuma orange trees on different rootstocks are tabulated for the three experimental orchards. The yield records extend over an eight-year period for the two orchards planted in 1929, and over a seven-year period for the one orchard planted in 1930. The different rootstocks caused striking effects in the size and production of the trees. The rootstocks of the sweet orange, mandarin orange, grapefruit, Rough lemon, and Sampson tangelo have consistently produced larger trees than those of the sour orange. The trifoliate and the citrange rootstocks have produced smaller trees than the sour orange. There has not always been a positive correlation, however, between the size of the trees on different rootstocks and the volume of production.

The sweet orange has, almost without exception, produced somewhat more fruit than the other rootstocks commonly used with the Satsuma orange. The five different sweet orange stocks reacted very similarly, all producing large, vigorous trees, with good yields and good quality and grade of fruit. Only a few Satsumas are grown in California, but the limited experience of growers tends to favor the use of sweet orange stock, and this experience is supported by the experiments reported here.

Of the four sour orange varieties tested as rootstocks with the Satsuma, the Brazilian and the Standard gave the best yields, and the trees on these stocks, when pulled at the orchard ages of nine and ten years, were all in good, vigorous condition. The trees on the Rubidoux sour stock were in poor condition, however, and those on African sour were either nearly dead or in very poor condition at the end of the tenth year. The opinion commonly held (Swingle, 1909) is that the sour orange is unsatisfactory as a stock for the Satsuma, but the results of the present experiments gave no indication of unsatisfactory reactions with Brazilian or Standard sour, except that the trees were somewhat smaller than those on sweet orange rootstock, and the yields were less.

The five mandarin varieties tested as rootstocks with the Satsuma produced trees approximately the same size as those on sweet orange or Rough lemon, and they were vigorous and healthy, with normal bud unions. The King and Cleopatra mandarin stocks gave the best yields in the group, but these yields were not equal to those of the sweet rootstock trees. The yields, in general, were about the same as those from the best strains of sour stocks. The trees on trifoliate rootstock were dwarfed by the stock, but produced nearly as much fruit as the larger trees on Standard sour orange or on mandarin roots.

The five citranges used as rootstocks have produced extremely variable results, judging from the size of the trees and the resulting yields. This would be expected from the great differences in citranges (see Vol. I, pp. 654 ff.). The trees on Morton and Savage citrange stock were vigorous, and the former produced trees nearly standard in size; but trees on Rusk, Cunningham, and

TABLE 13

EFFECT OF ROOTSTOCK ON SIZE AND YIELD OF OWARI SATSUMA ORANGE, RIVERSIDE, CALIFORNIA

Orchard planted in 1929 with one-year-old budlings

| Rootstock species and variety | Number of trees[a] | Average size of trees[b] in 1939 (sq. cm.) | Average annual yield per tree (pounds) | | |
|---|---|---|---|---|---|
| | | | 1931–1934 | 1935–1938 | 1931–1938 |
| Sweet orange: | | | | | |
| Oroville | 10 | 116 | 27 | 96 | 61 |
| Unselected | 11 | 119 | 24 | 102 | 63 |
| Average | | 118 | 25 | 99 | 62 |
| Sour orange: | | | | | |
| Standard | 10 | 91 | 22 | 82 | 52 |
| Rough lemon | 11 | 106 | 36 | 71 | 53 |
| Trifoliate orange | 16 | 50 | 22 | 75 | 48 |
| Sampson tangelo | 9 | 123 | 19 | 91 | 55 |

Orchard planted in 1929 with two-year-old budlings

| Rootstock species and variety | Number of trees[a] | Average size of trees[b] in 1939 (sq. cm.) | Average annual yield per tree (pounds) | | |
|---|---|---|---|---|---|
| | | | 1931–1934 | 1935–1938 | 1931–1938 |
| Sweet orange: | | | | | |
| C.E.S. seedling 362 | 11 | 116 | 37 | 114 | 75 |
| Sour orange: | | | | | |
| African | 11 | 72 | 25 | 65 | 45 |
| Brazilian | 15 | 85 | 22 | 83 | 52 |
| Rubidoux | 8 | 56 | 22 | 56 | 39 |
| Average | | 74 | 23 | 70 | 46 |
| Mandarin: | | | | | |
| Cleopatra | 11 | 110 | 20 | 87 | 53 |
| Citrange: | | | | | |
| Cunningham | 11 | 46 | 30 | 73 | 51 |
| Savage | 17 | 64 | 34 | 91 | 63 |
| Average | | 57 | 32 | 84 | 58 |
| Trifoliate orange | 11 | 61 | 24 | 73 | 48 |

TABLE 13—(*Continued*)

EFFECT OF ROOTSTOCK ON SIZE AND YIELD OF OWARI SATSUMA ORANGE, RIVERSIDE, CALIFORNIA

Orchard planted in 1930 with one-year-old budlings

| Rootstock species and variety | Number of trees[a] | Average size of trees[b] in 1938 (sq. cm.) | Average annual yield per tree (pounds) | | |
|---|---|---|---|---|---|
| | | | 1932–1935 | 1936–1938 | 1932–1938 |
| Sweet orange: | | | | | |
| C.E.S. seedling 358 | 15 | 92 | 29 | 94 | 57 |
| Mandarin: | | | | | |
| Dancy | 16 | 93 | 19 | 69 | 40 |
| King | 15 | 100 | 30 | 80 | 51 |
| Willow Leaf | 16 | 101 | 25 | 74 | 46 |
| Average | | 98 | 25 | 74 | 46 |
| Grapefruit: | | | | | |
| McCarty | 14 | 106 | 19 | 95 | 52 |
| Citrange:[c] | | | | | |
| Morton | 16 | 84 | 32 | 142 | 79 |
| Rusk | 11 | 47 | 27 | 70 | 45 |
| Rusk cuttings | 10 | 54 | 33 | 79 | 53 |
| Average | | 65 | 30 | 104 | 62 |
| Rough lemon | 11 | 89 | 43 | 92 | 64 |
| *Citrus Webberii* | 12 | 65 | 20 | 73 | 43 |
| Calamondin | 16 | 76 | 17 | 70 | 40 |

[a] At the end of the experiment.
[b] Comparative tree size indicated by area of cross section of trunk six inches above bud union.
[c] Of trees on Coleman citrange rootstock in this orchard, 60 per cent died in one to seven years; no data reported.

Colcman were decidedly dwarfed, approaching the degree of dwarfing exhibited by the trifoliate orange. All exhibited some degree of stock overgrowth. The Coleman citrange was so markedly incompatible with the Satsuma orange that the trees failed to live through the short period of this experiment. The Morton citrange rootstock, on the other hand, even though it dwarfed the Satsuma trees slightly, in comparison with the sweet orange stock as a standard, produced trees which were significantly more productive than those on sweet orange. If it were practical to obtain seedling nursery stock of the Morton citrange, it seems probable that this would be the best stock to use for Satsumas, when grown under the conditions of this experiment. The Savage citrange also gives some promise as a rootstock, for it yielded 84 per cent as much fruit as the sweet orange and 19 per cent more than the Cleopatra mandarin, which produced as much as, or more than, the several sour orange rootstock trees tested. We believe that the Savage citrange merits limited use, and that if the trees are planted close enough together they will probably give a satisfactory yield per acre. The Savage citrange has been very resistant to brown-rot gummosis in other rootstock trials (see grapefruit, p. 209), and is possibly more resistant than Cleopatra mandarin.

The trifoliate orange, which is probably the rootstock most commonly employed for Satsuma varieties in Japan and the United States, produced 78 per cent as much fruit as the trees on sweet orange, and thus indicated only medium yield in comparison with the latter stock.

The relative production of the trees on Rough lemon was not consistent in the different plantings; it apparently does not have much merit as a rootstock for the Satsuma. The trees were vigorous, healthy, and standard in size, but the fairly favorable yield reaction was offset by the poor character of the fruit, which tends to be coarse, rough, and conspicuously necked. Another factor against the use of Rough lemon is the frost-tenderness of the stock and its effect on the top. This was clearly shown in an experimental orchard planted in central California (Oroville). Here, in a severe freeze the trees on trifoliate rootstock were only moderately injured whereas those on Rough lemon were severely injured (see chap. ii, p. 95; also Webber, 1935). As the Satsuma succeeds best in northern or comparatively cold citrus sections, this tenderness of the Rough lemon should exclude it from use as a stock for the Satsuma.

The Satsuma on Sampson tangelo, which is promising as a rootstock for lemons and Valencia orange, produced 89 per cent as much fruit as Satsuma on sweet orange. This would indicate that the Sampson is a fairly good stock for Satsumas, though probably inferior to sweet orange.

The trees on *Citrus Webberii* and Calamondin gave yields, respectively, of only 75 and 70 per cent as much as those of the trees on sweet orange, and with each of these rootstocks the trees were below standard size, though not dwarfed as much as those on trifoliate stock.

*Conclusions.*—The Satsuma on sweet orange rootstock at Riverside yielded more fruit than Satsuma on any other rootstock except Morton citrange. Some strains of sour orange were unsatisfactory; others, such as the Brazilian and Standard sour, produced good trees but were comparatively low in yield.

Trifoliate orange rootstock stunts the Satsuma orange trees, but if they are planted close together the yield per acre may be comparable to the acre yield of trees on sweet orange planted a greater distance apart. In a cold location, or in heavy soil in which the trees would be susceptible to brown-rot gummosis, the trifoliate would be desirable. Sampson tangelo gives some promise as a rootstock.

Rough lemon does not appear to have any special merit as a rootstock for the Satsuma orange in California. The inferior quality of the fruit from such trees, and their susceptibility to frost injury, count against this stock.

Morton citrange merits limited commercial trial when it is possible to obtain a sufficient amount of seed for growing the rootstock seedlings.

The Savage rootstock also merits commercial trial with the Satsuma orange because of the comparatively high yield of fruit on trees of this stock and its comparative resistance to brown-rot gummosis.

## ROOTSTOCKS FOR OTHER MANDARIN AND TANGERINE VARIETIES

The evidence available on the best stocks to employ for such mandarin and tangerine varieties as Dancy, Clementine, King, Emperor, and others is based almost wholly upon the practical experience of growers. In California such varieties are propagated almost wholly on sweet orange or sour orange stocks, which apparently give fairly satisfactory results, but the acreage grown is

small and unimportant. The trees on sweet stock grow somewhat larger than those on sour.

In Florida, mandarin and tangerine varieties are propagated mainly on sour orange, Rough lemon, or Cleopatra mandarin stocks, the type of stock used depending on the character of the soil where the trees are to be grown. All mandarin varieties grow vigorously on Rough lemon, but the fruits, like those of the Satsuma on this stock, are prone to be coarse and necked and to begin drying out rather early. According to Hume (1926), however, "Dancy tangerines of high grade may be grown on Rough-lemon stock. The great difficulty in growing good tangerines is to produce them large enough, and Rough-lemon stock aids to this end."

Provan (1933) has stated that, in Australia, where mandarins have been extensively grown, the early Imperial mandarin on Rough lemon stock shows a very large overgrowth of the stock, and the trees apparently decline and die at an early age. Such declined trees have been restored by top-working to Valencia orange.

In South Africa, tangerine varieties have been propagated almost exclusively on Rough lemon stocks, which seem to have given satisfactory results. In 1925, seventy-year-old trees of the Cape tangerine on Rough lemon were still in robust health. In China, mandarin oranges are widely grown and are mainly propagated on rootstocks of some type of mandarin.

## ROOTSTOCKS FOR MARSH GRAPEFRUIT

The California rootstock experiments with Marsh grapefruit which are summarized here were conducted in two orchards that were approximately duplicates, one at Riverside, on Ramona loam soil, and the other at Brawley,[1] on Holtville silty clay loam.

*Average size and yield of trees on different rootstocks.*—In table 14, average tree sizes and average annual yields of Marsh grapefruit trees on different rootstocks are tabulated for the two experimental orchards. The yields extend over a ten-year period, with the one exception of the orchard planted at Brawley in 1929, for which records are available for only nine years. One of the most obvious effects of the rootstocks is upon the size of the trees, as shown by observation and by the comparative areas of cross sections of the scion trunks.

The data in table 14 show that in the orchards planted in 1928 the sweet orange rootstock produced the largest trees. At Riverside, the average size of the trees on the sweet orange rootstocks is 24 per cent greater than that of the trees on the sour orange; and at Brawley, 20 per cent greater. The varieties of citrange rootstock produced medium-to-small, variable trees. In comparison with sweet orange stock, the trifoliate rootstock had an extreme dwarfing effect on the grapefruit trees (see figs. 83 and 84). The dwarfing effect of this particular strain of trifoliate stock was exhibited in a much greater degree with grapefruit than with Valencia orange or with Washington Navel orange. The additional data from the orchards planted in 1929 indicate

[1] These localities differ greatly in their climatic conditions. (See Vol. I, "The interior valley section," p. 77, and "The desert section," p. 78.)

TABLE 14

EFFECT OF ROOTSTOCK ON SIZE AND YIELD OF MARSH GRAPEFRUIT TREES, RIVERSIDE AND BRAWLEY, CALIFORNIA

Orchards planted in 1928

| Rootstock species and variety | Riverside: Number of trees[a] | Riverside: Average size of trees[b] in 1939 (sq. cm.) | Riverside: Average annual yield per tree (pounds) 1931–1935 | Riverside: Average annual yield per tree (pounds) 1936–1940 | Riverside: Average annual yield per tree (pounds) 1931–1940 | Brawley: Number of trees[a] | Brawley: Average size of trees[b] in 1939 (sq. cm.) | Brawley: Average annual yield per tree (pounds) 1931–1935 | Brawley: Average annual yield per tree (pounds) 1936–1940 | Brawley: Average annual yield per tree (pounds) 1931–1940 |
|---|---|---|---|---|---|---|---|---|---|---|
| Sweet orange: | | | | | | | | | | |
| C.E.S. seedling 362 | 15 | 255 | 156 | 256 | 206 | 15 | 380 | 214 | 405 | 309 |
| Homosassa | 10 | 241 | 142 | 238 | 190 | 9 | 382 | 204 | 344 | 274 |
| Average | | 249 | 150 | 249 | 200 | | 381 | 210 | 382 | 296 |
| Sour orange: | | | | | | | | | | |
| African | 10 | 194 | 116 | 207 | 161 | 20 | 302 | 164 | 327 | 245 |
| Brazilian | 10 | 214 | 152 | 242 | 197 | 15 | 349 | 200 | 403 | 301 |
| Rubidoux | 15 | 199 | 137 | 250 | 193 | 20 | 306 | 176 | 367 | 271 |
| Standard | 9 | 196 | 139 | 243 | 191 | 13 | 337 | 190 | 383 | 286 |
| Average | | 201 | 136 | 237 | 186 | | 320 | 180 | 366 | 273 |
| Mandarin: | | | | | | | | | | |
| Clementine | 10 | 217 | 121 | 227 | 174 | 14 | 286 | 139 | 270 | 204 |
| Cleopatra | 20 | 268 | 152 | 254 | 203 | 30 | 346 | 160 | 339 | 249 |
| Average | | 251 | 142 | 245 | 193 | | 327 | 153 | 317 | 235 |
| Citrange: | | | | | | | | | | |
| Cunningham | 9 | 127 | 112 | 172 | 142 | 10 | 183 | 154 | 212 | 183 |
| Savage | 10 | 160 | 117 | 188 | 152 | 15 | 210 | 147 | 286 | 216 |
| Average | | 144 | 115 | 180 | 147 | | 199 | 150 | 256 | 203 |
| Lemon shaddock | 10 | 175 | 87 | 189 | 138 | 14 | 260 | 152 | 313 | 232 |
| Trifoliate orange | 10 | 65 | 61 | 116 | 88 | 10 | 125 | 78 | 151 | 114 |
| Shaddock × St. Michael, hybrid | 15 | 143 | 99 | 201 | 150 | 9 | 262 | 162 | 321 | 241 |
| Rough lemon | 24 | 200 | 133 | 250 | 191 | 20 | 339 | 213 | 457 | 335 |

Orchards planted in 1929

| Rootstock species and variety | Riverside: Number of trees[a] | Riverside: Average size of trees[b] in 1940 (sq. cm.) | Riverside: Average annual yield per tree (pounds) 1932–1936 | Riverside: Average annual yield per tree (pounds) 1937–1941 | Riverside: Average annual yield per tree (pounds) 1932–1941 | Brawley: Number of trees[a] | Brawley: Average size of trees[b] in 1940 (sq. cm.) | Brawley: Average annual yield per tree (pounds) 1932–1936 | Brawley: Average annual yield per tree (pounds) 1937–1940 | Brawley: Average annual yield per tree (pounds) 1932–1940 |
|---|---|---|---|---|---|---|---|---|---|---|
| Sweet orange: | | | | | | | | | | |
| Oroville | 15 | 264 | 136 | 273 | 204 | 12 | 366 | 172 | 412 | 272 |
| Seedlings (mixed) | 10 | 245 | 142 | 274 | 208 | 15 | 388 | 176 | 448 | 297 |
| Average | | 256 | 138 | 273 | 206 | | 378 | 174 | 431 | 291 |
| Sweet lemon: | | | | | | | | | | |
| Millsweet | 10 | 117 | 51 | 124[c] | 80 | 6[d] | 270 | 187 | 426 | 293 |
| Sampson tangelo | 14 | 272 | 137 | 249 | 193 | 15 | 403 | 159 | 427 | 294 |
| Rough lemon | 15 | 222 | 135 | 229 | 182 | 11 | 369 | 239 | 570 | 392 |

TABLE 14—(*Continued*)

EFFECT OF ROOTSTOCK ON SIZE AND YIELD OF MARSH GRAPEFRUIT TREES, RIVERSIDE AND BRAWLEY, CALIFORNIA

Orchard planted in 1930

| Rootstock species and variety | Riverside | | | | |
|---|---|---|---|---|---|
| | Number of trees[a] | Average size of trees[b] in 1939 (sq. cm.) | Average annual yield per tree (pounds) | | |
| | | | 1933–1937 | 1938–1942 | 1933–1942 |
| Sweet orange: | | | | | |
| C.E.S. seedling 358 | 15 | 209 | 169 | 287 | 228 |
| Sour orange: | | | | | |
| Bittersweet | 10 | 157 | 143 | 249 | 196 |
| Mandarin: | | | | | |
| Dancy | 15 | 192 | 151 | 248 | 190 |
| Grapefruit: | | | | | |
| McCarty | 15 | 193 | 148 | 240 | 194 |
| Pernambuco | 20 | 215 | 144 | 234 | 189 |
| Tresca | 19 | 218 | 176 | 263 | 210 |
| Average | | 210 | 156 | 246 | 201 |
| Calamondin | 11 | 140 | 88 | 98 | 92 |
| Rough lemon | 15 | 211 | 202 | 260 | 231 |

[a] At the end of the experiment.
[b] Comparative tree size indicated by area of cross section of trunk six inches above bud union.
[c] Five trees died during this period.
[d] Nine of the original fifteen trees in this orchard died during the ten years 1932–1941.

that the Sampson tangelo makes a slightly larger tree than the sweet orange or Rough lemon rootstock.

By inspection of table 14 it can be seen that there is a very high degree of correlation between average annual yield and tree size. Individual tree yields are only one consideration, however, in evaluating the merit of a rootstock. Medium-sized trees may be planted closer together than larger trees, and thus, with more trees to the acre, the yields from medium-sized trees, on an acre basis, may be equal to or even greater than those from larger ones planted farther apart. Comparison of the sweet orange with the sour orange rootstock, both at Riverside and at Brawley, illustrates this point. In the Brawley orchards, for example, the sweet orange stock trees are 20 per cent larger than the sour orange, but in the ten-year period 1931–1940, inclusive, they produced only 8 per cent more fruit. There are also disadvantages and extra cultural expenses in handling very large trees.

The resistance to disease and the relative productiveness of trees on sour orange rootstock has caused this stock to be generally used for grapefruit orchards in California, Arizona, and Texas. The data in table 14 justify the continuation of this practice where the cultural operations and natural conditions make resistance to disease an important consideration.

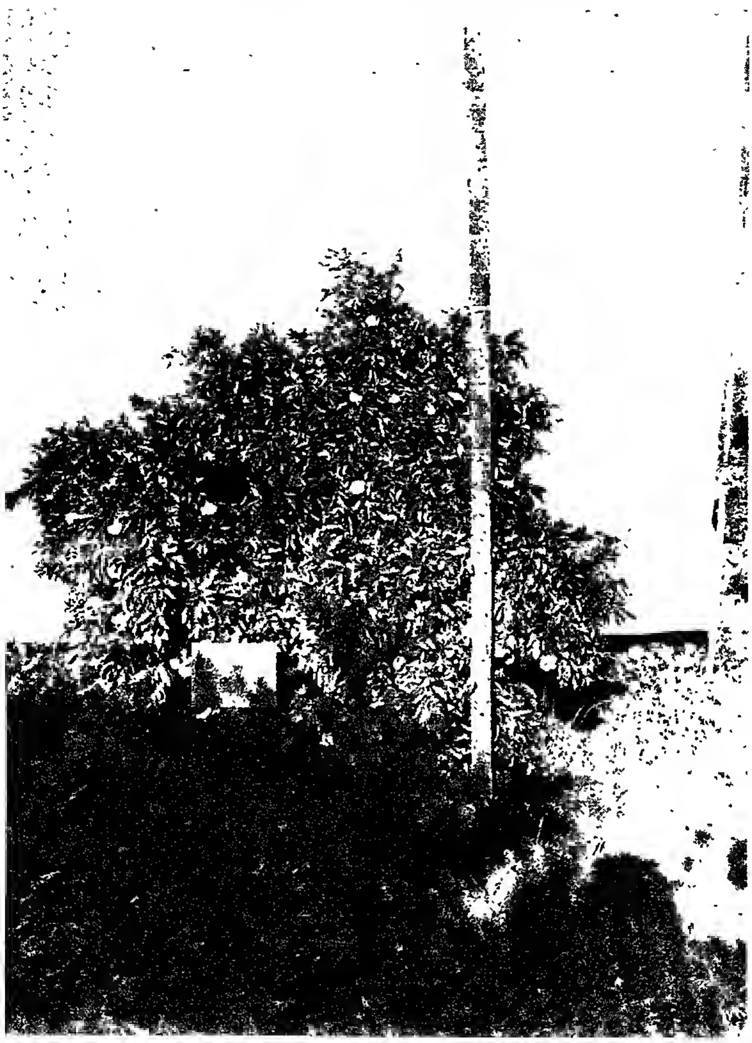

Fig. 83. Sixteen-year-old Marsh grapefruit budded to trifoliate orange rootstock, in experimental orchard at the Citrus Experiment Station, Riverside, California.

The Rough lemon rootstock trees were planted in the Riverside orchards in each of the three years 1928, 1929, and 1930; in the Brawley orchards plantings were made only in 1928 and 1929. There are thus five plantings of Rough lemon comparable with corresponding plantings of sweet orange rootstocks. At Riverside, the trees on Rough lemon have produced practically the same yields as those on sweet orange. At Brawley, the Rough lemon was probably

Fig. 84. Sixteen-year-old Marsh grapefruit budded to sweet orange 362 rootstock, in experimental orchard at the Citrus Experiment Station, Riverside, California.

significantly more productive only in the 1929 orchard, where it exceeded the average nine-year yields of the sweet orange trees by 35 per cent. Just why the Rough lemon should have been so irregular in these trials is not known; however, it does not appear to be a particularly desirable stock for

grapefruit in California. Rough lemon rootstock renders the grapefruit tree more susceptible to frost, as has been observed with other varieties of citrus on this same stock. The effect of the Rough lemon stock on the grapefruit tree, as compared with that of the sour orange stock, is illustrated in figure 70. Rough lemon stock is not especially resistant to brown-rot gummosis and produces fruit particularly low in quality.

A promising stock which merits commercial trial, and which is very nearly equal to sour orange stock in disease resistance, is the Cleopatra mandarin. This stock also produces normal-sized trees and crops, compared with the sweet orange stock as a standard. Two other stocks which have been as resistant to brown-rot gummosis as the sour orange in this experiment, but which have some depressing effect on the size of the trees, are the Savage citrange and the shaddock × St. Michael hybrid. Trees on these two rootstocks are more productive than those on sweet orange roots, in relation to size. To illustrate this principle, the trees on sweet orange rootstock at Riverside are 56 per cent larger than those on Savage citrange, but have produced in ten years only 32 per cent more fruit; at Brawley, the trees are 81 per cent larger trees, but have produced only 37 per cent more fruit. The relative size of sixteen-year-old Marsh grapefruit trees on sweet orange stock and on Savage citrange stock can be seen by comparing figures 84 and 85. There may be a place, under certain commercial cultural conditions, and in home gardens, for these very productive, medium-sized trees on relatively disease-resistant rootstocks. The Marsh grapefruit trees on Savage citrange roots are normal and healthy in every respect, even though smaller in size than comparable trees on sweet rootstocks. The overgrowth of the Savage citrange rootstock at the bud union is notably less than that of the trifoliate rootstock with Marsh grapefruit tops.

The sweet lemon stock (var. Millsweet) has been relatively productive in the 1929 Brawley orchard, so far as the surviving trees are concerned; this is a short-lived, disease-susceptible rootstock, however, not adapted to the conditions under which it was tried. More than half the trees on this rootstock in the Brawley orchard died in the first twelve years.

A comparison of rootstock varieties within the respective species indicates that differences in the sweet orange selections used in this experiment are probably within the realm of chance. The particular varieties or seedling trees used were of practically equal vigor and have resulted in orchard trees of essentially equal productiveness. This should not be taken to mean that selection for superior rootstock sources within the species is futile, but rather that the four used in this experiment probably do not include the extremes and thus do not show a significant difference. The results in the use of the four selections within the sour orange species show a significant difference. The African sour orange has produced normal-sized trees for the species but is exceeded in production by the other sour orange stocks by 20 per cent, more or less. The yields of the other three sour orange stocks have not varied greatly. In the mandarin species, the Cleopatra variety produces somewhat larger, more productive trees than the Clementine variety. Of the citranges tested, the Savage has some advantages over the Cunningham: it is definitely more pro-

Fig. 85. Sixteen-year-old Marsh grapefruit tree on Savage citrange rootstock.

ductive in the Brawley orchard, and the trees are more vigorous. As noted below (p. 209), the fruit on the Savage rootstock also is of especially high quality.

Yields from an orchard planted at Riverside in 1930 are presented in table 14. The main interest in these data lies in a comparison between yields of trees

on a sweet orange rootstock and on three varieties of grapefruit. The average yields of the grapefruit stock trees are generally less than those of the sweet orange, though the small differences may have very little significance. Within the species there seems to be very little choice between these three varieties of grapefruit used as rootstocks. Yields of a small planting of Duncan grapefruit stock trees in the 1928 orchard, which are not included in table 14, were also less than those of the sweet orange.

The Dancy mandarin trees are slightly less vigorous and less productive than the sweet orange rootstock trees. Inasmuch as Dancy is about as susceptible to brown-rot gummosis as sweet orange (Klotz and Fawcett, 1930), there seems to be no advantage in its use.

Of the stocks tested, both at Riverside and at Brawley, the trifoliate orange was among the lowest in yield capacity. The trifoliate stocks exhibited marked overgrowth, and the tops were rather sickly in appearance and much dwarfed, the average height and diameter being less than half those of standard-sized trees. Nevertheless, all trees were living at the end of the fourteenth year and were bearing large crops of fruit, in comparison with their size.

*Influence of rootstock on fruit character.*—Although it is well known that fruit character is at times markedly influenced by the rootstock, the observations and studies that have thus far been made on the fruits of grapefruit trees in this series of rootstock tests have not revealed many changes that could be expected to affect the market value of the fruit. In general, the grapefruits produced on sweet orange, sour orange, grapefruit, and mandarin orange stocks are so similar in appearance, size, and quality that no difference has been observed that could be considered commercially important.

In some seasons it has been clearly noticeable that the fruits produced on trifoliate orange stocks were more uniform in size and slightly smaller than those on most other stocks, and that they were particularly smaller and more uniformly globose or oblate than those on Rough lemon stocks. The fruits on trifoliate are smoother and more solid, with slightly thinner peel, than those on Rough lemon, and, in general, are of slightly superior quality. The trifoliate orange and the Rough lemon seem to represent the two extremes among the rootstocks tested, with respect to their tendencies in the expression of these characters. It is also noteworthy that the Savage citrange has an influence on the fruit similar to that of the trifoliate orange. The Savage citrange merits careful consideration as a rootstock for the grapefruit.

The factors emphasized in the preceding paragraph are also indicated by the data obtained by Sinclair and Bartholomew (1944) in their chemical studies of the fruits from a number of these rootstock varieties at both Riverside and Brawley. These data are illustrated plainly by the graphs in figure 86. The averages of the analyses for each rootstock are indicated in position on each graph by a single dot above the stock name. Each dot represents the average of different analyses of samples taken from ten trees during two consecutive years, and may therefore be considered as representing very accurately the differences that normally exist.

In the uppermost graph (fig. 86), for total acids (as citric), it will be noted

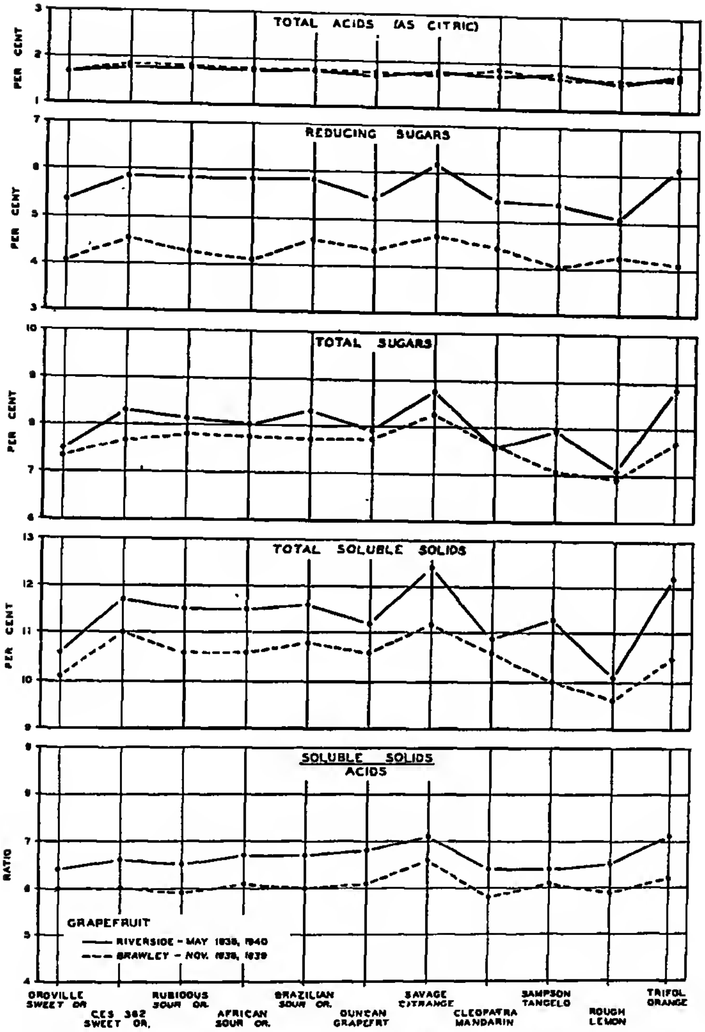


Fig. 86. Relative concentrations of certain soluble organic constituents in the juice of mature fruits from Marsh grapefruit trees budded on different stocks and grown in plots at Riverside and Brawley. The mean value for two years' results is recorded for each stock. (From Sinclair and Bartholomew, 1944, p. 141.)

that the two lines representing the Riverside and Brawley plots are nearly horizontal and almost superimposed, showing that acid content was not materially affected by the stock or the location. The slightly lower acid content in the fruits on Rough lemon is probably significant, but at most the difference is slight.

In the three graphs (fig. 86) showing the percentages of reducing sugars, total sugars, and total soluble solids, the lines are very similar, as would be expected, nearly paralleling one another but showing with few exceptions notably higher percentages in the Riverside samples.[1] The outstanding rootstock influences here are the very high percentages of sugars and soluble solids shown by the fruits on the trifoliate orange and Savage citrange stocks and the very low percentages exhibited by the fruits on Rough lemon stocks. These reactions were the same at Riverside and at Brawley.

Another rather striking variation is the much higher content of sugars and of total soluble solids shown by the fruits grown on C.E.S. 362 sweet orange stock, as compared with that of fruits grown on the Oroville sweet orange. As this reaction is the same at Riverside and at Brawley, during the two years in which tests were made, it would seem to be a characteristically different reaction of the two sweet stocks. As the yield capacities of the two stocks are practically the same, this would seem to constitute a definite feature favoring the seedling 362 over the Oroville as a sweet orange rootstock for the grapefruit. This indicates again that completeness of data is necessary for accurate judgment of the performance of a rootstock.

The bottom graph (fig. 86), showing the ratios of soluble solids to acids of the fruit on different rootstocks, indicates little variation. The two high ratios exhibited by trifoliate orange and Savage citrange indicate the outstanding quality of the fruits on these stocks, which are also comparatively high in total sugars and total soluble solids. The medium ratio exhibited by the fruits on Rough lemon seems to indicate a fairly good quality, but is somewhat misleading. The fruits on this stock are low in sugar and soluble solids, but as they are also low in acid content the ratio shows about as high as on most other stocks. The ratio of solids to acids is not, here, a good indication of quality.

*Prevalence of brown-rot gummosis.*—The experimental orchard at Brawley provided an opoportunity to observe the prevalence of gummosis under conditions that were extremely favorable for the development of this troublesome disease: (1) the grapefruit trees were basin-irrigated and were thus repeatedly wet at the base of the trunk, and (2) there happened to be an especially virulent strain of *Phytophthora* sp. in this orchard. Data on the prevalence of gummosis were obtained in coöperation with Dr. L. J. Klotz during the spring of 1944. This was approximately two years after a bad outbreak in this particular orchard.

The data in table 15 show the effect of the different rootstocks on the prevalence of this disease. The total number of trees alive at the end of the experiment, and the percentage of these trees free from gummosis, are recorded for the several rootstocks. Trees on varieties of sweet orange stocks were grouped together, as there was very little varietal difference. The same was true of the trees on sour orange. Only 49 per cent of the trees on sweet orange

[1] The Brawley fruit was harvested earlier in the ripening period than the Riverside fruit; this accounts for its consistently lower content of sugars and soluble solids. The data here presented should not be understood as indicative of the fruit quality typical of these two districts.

stock were free from disease, whereas 97 per cent of those on sour orange were healthy. The difference in the mandarin varieties was in harmony with previous studies (Klotz and Fawcett, 1930), the percentage of the Clementine variety that remained healthy being much smaller than that of the Cleopatra. The trees on trifoliate rootstock, on the two varieties of citranges, and on the hybrid, shaddock × St. Michael, were 100 per cent healthy. The trees on Rough lemon were comparable to those on Cleopatra mandarin, with 87 per cent of the trees healthy on both of those rootstocks.

TABLE 15

EFFECT OF DIFFERENT ROOTSTOCKS ON PREVALENCE OF BROWN-ROT GUMMOSIS ON SIXTEEN-YEAR-OLD GRAPEFRUIT TREES

| Rootstock species and variety | Number of trees alive at end of experiment (1944) | Percentage of trees free from brown-rot gummosis |
|---|---|---|
| Sweet orange | 53 | 49 |
| Sour orange | 69 | 97 |
| Mandarin: | | |
| Clementine | 13 | 38 |
| Cleopatra | 30 | 87 |
| Trifoliate orange | 10 | 100 |
| Rough lemon | 31 | 87 |
| Citrange: | | |
| Cunningham | 10 | 100 |
| Savage | 15 | 100 |
| Sampson tangelo | 16 | 31 |
| Shaddock × St. Michael, hybrid | 10 | 100 |

In other experiments Sampson tangelo as a rootstock continued to show a resistance to the ordinary gummosis caused by *Phytophthora citrophthora,* approaching that of sour orange. To the *Phytophthora* isolated from Brawley, however, and under the climatic and soil conditions there, Sampson tangelo proved the most susceptible of the rootstocks used. The merit of the sour orange as a rootstock for grapefruit is further emphasized by these observations on disease resistance.

*Conclusions.*—In considering the various rootstocks used in the Marsh grapefruit experiment, we conclude that the sour orange is the best all-round rootstock for grapefruit. The trees on sour orange roots are somewhat smaller than those on sweet orange, but produce nearly as much fruit. The resistance of the sour orange root to brown-rot gummosis is an important consideration affecting the choice of this rootstock. In production, the African sour orange stock has been consistently inferior to the other varieties of sour orange used.

Of the stocks uncommonly used in California, the Cleopatra mandarin and the Savage citrange merit limited commercial trial. Both are relatively resistant to brown-rot gummosis, and the Savage citrange has produced fruit of higher quality than the average of other stocks.

Rough lemon stocks have produced yields comparable with those of sweet orange, but the quality of the fruit has been inferior to that from other stocks.

## ROOTSTOCKS FOR EUREKA AND LISBON LEMONS

The California rootstock experiments with Eureka and Lisbon lemons which are summarized here were conducted with comparable plots of trees planted in 1927 in two locations, at the Citrus Experiment Station, Riverside, and the Rancho Sespe, Fillmore.

Both orchards included Eureka and Lisbon lemons. Soil types and climatic conditions in the two orchards differed, however. The orchard at Riverside was on Ramona sandy loam; the one at Fillmore, on Yolo silt loam. The climate at Riverside is less humid, with higher maximum temperatures, than that at Fillmore, which is a more nearly coastal climate.

*The relation of rootstocks to lemon-tree decline.*—These two orchards at Riverside and at Fillmore became of increasing interest during the five-year period 1939–1943, as it became evident that the rootstocks strikingly affected the prevalence of lemon-tree decline, as well as the yields of fruit. The problem of lemon-tree decline in California has persisted as a general one, especially in the coastal areas and in orchards growing in the heavier loam and silty loam soils. Now that these experimental orchards may be classed as mature and in full bearing, observations on them are of practical value.

Lemon-tree decline in California has been considered from several points of view during the past twenty-five years or more, by investigators and by observant and thoughtful orchardists. The term "lemon-tree decline" is rather generally and loosely used to describe an involved problem, any one of the factors of which may bring on the adverse condition. The symptoms of the decline are, in general, as follows. Usually at some time in the second decade of the growth of the orchard the affected trees show a tendency to shed their leaves prematurely. The remaining leaves on the trees turn yellowish bronze in color, but not necessarily mottled or chlorotic. The small lateral twigs become devitalized and die prematurely. The tops of the trees, especially, die back abnormally, and when these are removed by periodic pruning the top volume of affected trees becomes progressively smaller. New twig growth does not develop normally, and as a result there is a reduction in yield and the crop contains an excessive amount of small, "tree-ripe" lemons. These symptoms are not uniformly seen throughout the orchard, and certain trees, or perhaps the orchard as a whole, will show marked improvement during particular seasons. A relapse to the former condition is always a possibility, however.

The term "lemon-tree decline" may perhaps more properly be considered as descriptive of certain general clinical symptoms than of a specific condition due solely to one cause. To ascribe lemon-tree decline to any one factor is to oversimplify a really complex problem.

*Experience of commercial orchardists.*—Decline of lemon trees has been studied more in Ventura County than elsewhere in the State. It was recognized in the earliest years of the observations of the trouble that both the Lisbon and the Eureka varieties were subject to decline (Newman, 1926). The serious situation in Ventura County was extensively studied (Jensen, Wilcox, and

Foot, 1927) in Lisbon and Eureka orchards on sour orange rootstocks. Later, Webber (1928) wrote concerning decline that "many old lemon groves have exhibited a marked decline and a critical examination seems to indicate that at least a part of this decline is attributable to the lack of congeniality of the sour orange stocks on which the trees are propagated." Subsequent observations (Blanchard, 1931) emphasized that "sour root stock is probably the greatest factor responsible for the early decline of these trees, but along with it is the problem of soil moisture regulation."

The value of having the soils thoroughly dried out in the summer before each irrigation, as well as the value of severe pruning of affected trees, was stressed by Culbertson[1] (Blanchard, 1931). According to Jensen[2] (Blanchard, 1931), lemon trees on sour orange rootstock were very prone to decline in spite of careful irrigation, and he recommended that orchards be planted on sweet orange stock.

Even though the sour orange rootstock is an important factor in the equation, the inarching of such trees to other rootstocks failed to effect a recovery (Halma, 1932). A survey of a small number of orchards in the Upland area (Halma and Wilder, 1933) indicated that lemon trees on sour orange rootstock could be grown successfully, at least on very open gravelly soils, where both good and poor trees were observed to have grown to the age of twenty years or more on this stock.

The tree and fruit variation of strains within the Lisbon and Eureka varieties has been observed by several investigators (Shamel, Scott, Pomeroy, and Dyer, 1920), and the probable influence of such variations as another factor in lemon-tree decline has been pointed out (Halma, 1929).

The studies of infectious virus diseases by Fawcett (1939) suggest to us the possibility that such a disease as psorosis may also occasionally be a factor in lemon-tree decline. Foliage symptoms of psorosis, a disease transmissible by budding, are frequently observed in lemon trees. Fawcett (1939) states: "Although lemons, as a rule, are more tolerant to psorosis than oranges, nevertheless they often seem to be badly affected, especially on sweet stock, and may deteriorate finally on account of its presence." It seems probable that the shell-bark disease of lemon trees, which is so prevalent on the Eureka variety and the open-type Lisbon, is also an important factor in causing the trees to deteriorate and finally reach a state of decline.

One of the limitations of past reviews of the subject by most observers has been lack of information concerning the identity of the several strains of lemon varieties. The strains and varieties, as well as the original source of the rootstock, varied from orchard to orchard. It was thus impossible to make comparisons of one factor at a time. In the rootstock experiments reported here, all the trees were propagated with buds from one parent tree of the variety. Thus in these comparisons all factors other than the rootstocks are constant.

[1] James D. Culbertson, Manager of the Santa Paula Lemon Company property at Santa Paula, California.

[2] C. A. Jensen, Superintendent of the Limoneira Company properties at Santa Paula, California.

The results of these experiments confirm the earlier observations of many persons that the rootstock is at least one very important factor in lemon-tree decline. The problem here discussed seems specific for lemons and affects certain strains of the Lisbon and the Eureka varieties with about equal severity.

*Method of evaluating degree of lemon-tree decline.*—The method of grading used in evaluating the degree of lemon-tree decline made it possible to compute readily the average extent of the trouble in any group of trees. The orchards were surveyed annually, or oftener, and the individual trees were classified as follows: 0, tree normal; 1, tree subnormal in growth or color, at least in part; 2, tree subnormal in growth and color, as a whole; 3, same as 2,

TABLE 16

EFFECT OF ROOTSTOCK ON LEMON-TREE DECLINE IN EUREKA LEMON ORCHARD PLANTED AT THE SESPE RANCH, FILLMORE, CALIFORNIA, IN 1927

| Rootstock species | Number of trees[a] | Average degree of decline[b] | | | | | |
|---|---|---|---|---|---|---|---|
| | | Nov. 1938 | Nov. 1939 | Dec. 1940 | May 1941 | Nov. 1941 | Average |
| Sweet orange | 58 | 0.03 | 0.74 | 0.37 | 1.13 | 0.43 | 0.54 |
| Sour orange | 43 | 0.95 | 1.40 | 1.38 | 2.16 | 1.44 | 1.47 |
| Mandarin | 38 | 0.00 | 0.37 | 0.26 | 1.01 | 0.37 | 0.40 |
| Grapefruit and shaddock | 29 | 0.28 | 1.10 | 0.55 | 1.69 | 0.91 | 0.91 |
| Rough lemon | 15 | 0.40 | 1.77 | 1.30 | 2.47 | 1.20 | 1.43 |
| Sampson tangelo | 15 | 0.00 | 0.07 | 0.03 | 0.13 | 0.20 | 0.09 |

[a] At the end of the experiment.
[b] The degree of the lemon-tree decline has been rated as follows: 0.00, normal trees; 1.00, subnormal in growth or color in at least a part of the tree; 2.00, subnormal in growth and color of the tree as a whole; 3.00, subnormal in growth and color of the tree as a whole, with dead wood and evident subnormal size, indicating that the decline condition has existed for several years and is now present to an extreme degree.

but tree also carrying dead wood and subnormal in size, these conditions indicating that the decline had existed for several years and was present in an extreme degree at the time of grading.

The surveys have been made in the early winter, four or more observers working together on each survey. The data are obviously not based on exact measurements, but it is believed that these estimates, recorded over a period of several years, are a reliable index of the true situation. More than 800 trees were observed, and their condition was recorded annually during five or more years. Although the decline was first noted in 1936, when the trees were in their tenth year, it was not marked enough to permit tabulation until 1938.

*Effect of rootstocks on lemon-tree decline in experimental orchards.*—The average degree of lemon-tree decline in the Eureka orchard at Fillmore, for various rootstocks, over a four-year period, is shown in table 16, as an illustration of the general observations. There was an upward trend in average decline during the years 1938 to 1941, inclusive. It is equally clear, however, that certain years were characterized by a much greater average decline than others, especially among rootstocks such as sweet orange, which show a partial resistance to this trouble. Except for a few trees, decline was notably worse in 1939 than in 1940.

The prevalence of decline in May, 1941, was much greater than it has been at any time before or since. This extreme condition followed a year of heavy rainfall and a period when both labor troubles and weather conditions prevented the picking of the fruit for several weeks after it was fully ripe on the trees. It seemed from this one casual observation that the prolonged delay in harvesting the fruit could have been one of the factors causing the extremely bad condition of the orchard. This fluctuation from year to year has been commonly noted by other observers. The records for individual trees are not shown in table 16, but they bring out the fluctuation strikingly. For example, a certain tree in class 2 in 1938 had recovered to normal (class 0) by 1941; another, in class 0 in 1938, was in class 1 in 1939, 0 in 1940, and 2 in 1941, and has since recovered to normal. Another tree which was in an advanced state of decline (class 3) in 1941 recovered to normal in 1944.

The average amount of decline among trees on the rootstocks of different species of citrus is in striking contrast in the orchard. The numerical grading brings out this fact somewhat less than actual observation of the trees; the differences are fairly constant, nevertheless, and the average numerical grades are offered as substitutes for illustrated records. It is clear from the data in table 16 that trees on sweet orange stock are much less subject to decline than those on sour orange or Rough lemon. Trees on mandarin orange and grapefruit stocks are intermediate between these two extremes, with mandarin the more resistant of the two.

The Sampson tangelo had not been used to any appreciable extent as a rootstock prior to these experiments. The resistance to decline of the lemon trees on this rootstock (fig. 87) has been in striking contrast to that of the trees on other rootstocks during this period of observation. Trees on Sampson tangelo stock began to show decline later even than those on sweet orange rootstock, and to much less degree.

The reasons why trees on Sampson tangelo root were so resistant to decline, at least until seventeen years of age, are not well understood, and nothing but conjecture can be offered at present. It has been found in some experiments that the fiber roots of Sampson tangelo are more resistant to injury by nitrite and also by *Phytophthora* spp. than are other rootstock species included in this orchard (Klotz and Sokoloff, 1943).

Similar comparisons were made between trees of plots in the Riverside orchard over an additional two-year period (1942–1943, inclusive). The degree to which the trees declined in the Riverside orchard, as a whole, is very much less than at Fillmore. Much the same relative results were observed with the various stocks in the Eureka plots at Riverside as at Fillmore. The notable exception is that the Rough lemon is much less prone to decline on the light soil at Riverside than on the silt loam at Fillmore. Although the Eureka trees on sour orange rootstock have not declined so much at Riverside as at Fillmore, the relative position, compared with the trees on sweet orange rootstock, is much the same. Several natural and cultural factors in the Riverside orchard differ from those in the orchard at Fillmore, perhaps the most basic one being the difference in soil. Both the Rough lemon and the sour orange rootstocks

are better adapted to the light, extremely well-drained soil at Riverside than to the silt loam soil at Fillmore. This is also in harmony with observations of Halma and Wilder (1935), who found healthy trees, twenty or more years old, growing on these two rootstocks in open gravelly soils of the Upland, California, region.

**Fig. 87. Eureka lemon tree on Sampson tangelo rootstock, free from any indication of lemon-tree decline for more than nineteen years.**

The trees on Sampson tangelo rootstock, especially those of the Eureka lemon variety, have shown less decline than the lemon trees on any other rootstock, and seem as well adapted to the light soil at Riverside as to the heavy silt loam at Fillmore. This rootstock merits commercial trial for both Eureka and Lisbon lemons. Although only forty trees (eighteen years old in 1944) were used in these particular experiments with lemons, observations in other experimental lemon orchards planted in 1929 confirm the desirability of using this rootstock for lemons, at least to a limited extent, commercially.

*Average size and yield of Eureka lemon trees on different rootstocks.*—Average tree sizes and average annual yields of Eureka lemon trees on the various rootstocks at Riverside are recorded in table 17. Tree sizes were determined in 1938. Yield data cover a thirteen-year period, 1931 to 1943, inclusive.

TABLE 17

EFFECT OF ROOTSTOCK ON SIZE AND YIELD OF EUREKA LEMON TREES, RIVERSIDE AND FILLMORE, CALIFORNIA

| Rootstock species and variety | Orchards planted in 1927 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Riverside | | | | | | Fillmore | | | | |
| | Number of trees[a] | Average size of trees[b] in 1938 (sq. cm.) | Average annual yield per tree (pounds) | | | | Number of trees[a] | Average size of trees[b] in 1938 (sq. cm.) | Average annual yield per tree (pounds) | | |
| | | | 1931–1935 | 1936–1940 | 1941–1943 | 1931–1943 | | | 1931–1935 | 1936–1941 | 1931–1941 |
| Sweet orange: | | | | | | | | | | | |
| Koethen | 10 | 268 | 174 | 336 | 364 | 280 | 10 | 228 | 247 | 370 | 314 |
| Bessie | 15 | 295 | 185 | 351 | 377 | 293 | 14 | 166 | 258 | 373 | 321 |
| C.E.S. seedling 302 | 15 | 265 | 167 | 314 | 344 | 264 | 10 | 221 | 208 | 305 | 261 |
| Homosassa | 10 | 284 | 177 | 327 | 338 | 272 | 10 | 237 | 224 | 314 | 273 |
| Madam Vinous | 20 | 289 | 182 | 317 | 335 | 269 | 20 | 251 | 251 | 346 | 302 |
| Average | | 281 | 178 | 329 | 352 | 276 | | 222 | 239 | 344 | 296 |
| Sour orange: | | | | | | | | | | | |
| African | 15 | 216 | 116 | 249 | 230 | 193 | 10 | 180 | 170 | 270 | 225 |
| Brazilian | 18 | 237 | 152 | 310 | 235 | 232 | 15 | 204 | 220 | 276 | 261 |
| Rubidoux | 33 | 236 | 147 | 308 | 266 | 236 | 14 | 182 | 178 | 239 | 211 |
| Average | | 232 | 141 | 295 | 249 | 225 | | 190 | 188 | 256 | 225 |
| Mandarin: | | | | | | | | | | | |
| Cleopatra | 10 | 270 | 105 | 326 | 375 | 252 | 10 | 224 | 168 | 343 | 263 |
| Dancy | 10 | 255 | 70 | 247 | 286 | 188 | | | | | |
| King | 10 | 283 | 99 | 295 | 293 | 219 | 14 | 220 | 204 | 329 | 272 |
| Oneco | 9 | 253 | 80 | 262 | 290 | 198 | 10 | 238 | 193 | 325 | 265 |
| Average | | 266 | 89 | 283 | 312 | 215 | | 226 | 190 | 332 | 267 |
| Grapefruit: | | | | | | | | | | | |
| C.E.S. seedling 343 | 10 | 233 | 145 | 326 | 328 | 257 | 10 | 196 | 201 | 327 | 270 |
| Duncan | | | | | | | 10 | 213 | 179 | 257 | 222 |
| Average | | | | | | | | 204 | 190 | 292 | 246 |
| Shaddock: | | | | | | | | | | | |
| Siamese | 10 | 189 | 61 | 208 | 231 | 157 | 10 | 167 | 139 | 221 | 184 |
| Rough lemon | 10 | 286 | 166 | 357 | 348 | 281 | 15 | 207 | 258 | 258 | 256 |
| Sampson tangelo | 15 | 323 | 116 | 301 | 360 | 243 | 15 | 264 | 237 | 381 | 316 |

[a] At the end of the experiment.
[b] Comparative tree size indicated by area of cross section of trunk six inches above bud union.

The Eureka trees on sweet orange rootstocks averaged 21 per cent larger than those on sour orange, while those on mandarin rootstocks were intermediate between the trees on sweet orange and on sour. The trees on rootstock of the one grapefruit variety in the Riverside Eureka plots averaged the same in size as the trees on the sour orange varieties.

The Eureka trees on Rough lemon rootstock at Riverside averaged only slightly larger than those on sweet orange, while those on Sampson tangelo

averaged 15 per cent larger. The trees on Siamese shaddock were smaller than those on any of the other rootstocks tested.

At Fillmore the Eureka trees on sweet orange were 17 per cent larger than those on sour orange, while Eureka trees on mandarin stocks averaged approximately the size of those on sweet orange. The average size of the trees on grapefruit was intermediate between that of trees on sweet orange and on sour orange. The trees on Rough lemon at Fillmore were considerably smaller than those on the same rootstock at Riverside, and averaged practically the same in size as the trees on grapefruit at Fillmore. Eurekas on Sampson tangelo at Fillmore, though larger than the trees on the other rootstocks, were about 18 per cent smaller than those on the same rootstock at Riverside.

Eureka trees on sweet orange at Riverside yielded a 23 per cent greater crop of fruit than those on sour orange, a difference which was proportional to the size of the trees. The yield of the trees on mandarin rootstock was practically the same as that of the trees on sour orange, although the trees on mandarin stock were larger. The trees on grapefruit rootstock were the same size as those on sour orange, but the average yield was about 14 per cent greater. The yield of trees on Rough lemon rootstock was slightly greater than that of trees on sweet orange and averaged more than that of any other rootstock at Riverside. The Eureka trees on Sampson tangelo were later in coming into full bearing than those on sweet orange rootstock, and produced less fruit during the first ten years. During the last eight years of the thirteen-year period, however, the trees on Sampson tangelo stock approximated the yields on sweet orange and on Rough lemon.

At Fillmore the Eureka lemon trees on Sampson tangelo rootstock yielded more fruit over an eleven-year period than those on any of the other stocks, and the trees averaged larger, though not so large as those on Sampson stock at Riverside, which had a comparatively smaller average yield. The trees on sweet orange at Fillmore produced almost as much fruit as the trees on Sampson tangelo, though they were about 16 per cent smaller.

Eureka trees on sour orange at Fillmore had a yield 24 per cent less than those on sweet orange, while the trees on mandarin rootstock were intermediate between those on sour and on sweet. The yield of Eureka trees on Rough lemon stock was approximately the same as that on mandarin stock. The yield on grapefruit averaged less than that on Rough lemon. Trees on Siamese shaddock had the lowest yield of all rootstock species and varieties tested.

*Average size and yield of Lisbon lemon trees on different rootstocks.*—Lisbon lemon trees in the planting at Riverside averaged nearly 20 per cent larger on sweet orange stock than on sour. (See table 18.) The trees on grapefruit averaged practically the same size as those on sour, and the trees on mandarin rootstock were slightly larger than those on sour orange. The Lisbons on Rough lemon and on Sampson tangelo were the same size and were slightly larger than those on sweet orange. The trees on Siamese shaddock were the smallest.

Although the Lisbon trees on sweet orange at Riverside were nearly 20 per cent larger than those on sour orange, they yielded only 15 per cent more.

TABLE 18

EFFECT OF ROOTSTOCK ON SIZE AND YIELD OF LISBON LEMON TREES, RIVERSIDE AND FILLMORE, CALIFORNIA

| Orchards planted in 1927 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Riverside | | | | | | Fillmore | | | | |
| Rootstock species and variety | Number of trees[a] | Average size of trees[b] in 1938 (sq. cm.) | Average annual yield per tree (pounds) | | | | Number of trees[a] | Average size of trees[b] in 1938 (sq. cm.) | Average annual yield per tree (pounds) | | |
| | | | 1931–1935 | 1936–1940 | 1941–1943 | 1931–1943 | | | 1931–1935 | 1936–1941 | 1931–1941 |
| Sweet orange: | | | | | | | | | | | |
| Koethen | 10 | 279 | 252 | 439 | 416 | 362 | 9 | 271 | 334 | 524 | 436 |
| Bessie | 10 | 264 | 251 | 474 | 417 | 375 | 9 | 276 | 349 | 519 | 441 |
| C.E.S. seedling 362 | 10 | 262 | 239 | 442 | 335 | 339 | 10 | 233 | 267 | 458 | 371 |
| Homosassa | 15 | 288 | 235 | 429 | 350 | 337 | 10 | 260 | 293 | 476 | 393 |
| Madam Vinous | 8 | 243 | 224 | 457 | 418 | 358 | 10 | 259 | 365 | 525 | 452 |
| Average | | 270 | 240 | 446 | 383 | 352 | | 261 | 321 | 500 | 418 |
| Sour orange: | | | | | | | | | | | |
| African | 10 | 217 | 101 | 339 | 255 | 262 | 10 | 211 | 314 | 393 | 357 |
| Brazilian | 15 | 227 | 230 | 365 | 308 | 300 | 15 | 221 | 303 | 381 | 346 |
| Rubidoux | 20 | 230 | 233 | 420 | 348 | 331 | 15 | 215 | 289 | 413 | 357 |
| Average | | 226 | 222 | 384 | 314 | 305 | | 216 | 300 | 396 | 353 |
| Mandarin: | | | | | | | | | | | |
| Cleopatra | 10 | 273 | 209 | 440 | 374 | 336 | 10 | 220 | 235 | 407 | 329 |
| King | 25 | 226 | 156 | 305 | 289 | 246 | 20 | 229 | 257 | 458 | 367 |
| Average | | 239 | 171 | 348 | 313 | 272 | | 226 | 250 | 441 | 354 |
| Grapefruit: | | | | | | | | | | | |
| C.E.S. seedling 343 | 10 | 249 | 202 | 411 | 414 | 331 | 10 | 225 | 310 | 441 | 380 |
| Duncan | 10 | 207 | 166 | 332 | 357 | 273 | 15 | 256 | 281 | 425 | 359 |
| Average | | 228 | 183 | 371 | 385 | 302 | | 244 | 293 | 431 | 367 |
| Shaddock: | | | | | | | | | | | |
| Siamese | 10 | 201 | 129 | 263 | 328 | 227 | 8 | 245 | 278 | 409 | 349 |
| Rough lemon | 14 | 274 | 266 | 380 | 363 | 332 | 15 | 238 | 319 | 331 | 326 |
| Sampson tangelo | 10 | 272 | 200 | 370 | 401 | 312 | 15 | 273 | 281 | 465 | 381 |

[a] At the end of the experiment.
[b] Comparative tree size indicated by area of cross section of trunk six inches above bud union.

The trees on mandarin produced 10 per cent less than those on sour orange, though the average tree size was larger. Lisbons on grapefruit equaled those on sour orange in yield, and the trees averaged the same size. Lisbon trees on Rough lemon and on Sampson tangelo produced somewhat less fruit than those on sweet orange. The average production of the trees on Siamese shaddock was lower than that of any others.

Lisbon trees on sweet orange rootstock at Fillmore averaged 21 per cent larger than the trees on sour orange or mandarin, which were about equal

in size. The Lisbons on grapefruit, Siamese shaddock, and Rough lemon were approximately equal in size and were intermediate in size between those on sour orange and on sweet. Lisbons on Sampson tangelo were slightly larger than those on sweet orange. The Lisbons on sweet orange at Fillmore produced 18 per cent more fruit than those on either the sour orange or the mandarin. The yield of Lisbons on Rough lemon was about 22 per cent less than that of trees on sweet orange, and the trees on Sampson tangelo averaged less than those on the sweet orange by 9 per cent.

*Conclusions.*—Eureka and Lisbon lemon trees have been affected by lemon-tree decline in the plantings both at Riverside and at Fillmore. The trees on Sampson tangelo rootstock have been the least affected, however, and are nearly resistant. The rootstocks, in decreasing order of resistance for Eurekas at Fillmore, are as follows: Sampson tangelo, mandarin orange, sweet orange, grapefruit, Rough lemon, and sour orange. Although both the Eureka and the Lisbon lemon have yielded equally as much fruit on sweet orange stock as on any other species or variety of rootstock, in districts subject to lemon-tree decline, there is an indication that Sampson tangelo would be the most profitable rootstock over the longest period. This conclusion is based on the greater resistance of this rootstock to decline, and on the fact that the yields of trees on Sampson tangelo have increased more during the last few years, in comparison with some of the other rootstocks.

Lemons on sour orange may be satisfactory in some locations, but would be unprofitable under conditions comparable to those of the Fillmore district. A specially selected grapefruit stock of known performance may prove satisfactory under certain conditions, as in the more interior climatic areas and in well-drained soils.

Rough lemon as a rootstock may be satisfactory under certain conditions of climate and soil, but should not be tried in orchards having heavy soils. Lemon trees on mandarin stock were not so productive, on the average, as those on sweet orange, but they were relatively resistant to lemon-tree decline; this should justify limited commercial trial. The Cleopatra mandarin rootstock, especially in the latter part of the period of observations, and with the Eureka tops, seemed equal or superior to the sweet orange rootstock.

## ROOTSTOCKS FOR LIMES

Lime trees have been grown mostly as seedlings. Thus there has been only limited experience with these trees on the different rootstocks. In southern Florida the lime trees which have been budded have been most commonly propagated on Rough lemon roots. This has been considered the best stock for both the Tahiti and the Mexican groups of limes. The grapefruit as a rootstock is also considered good (Steffani, 1934). The sour orange is not considered a suitable rootstock for limes in Florida (Hume, 1926). In California, however, sour orange stock has been the principal one used, though sweet orange rootstock is probably more generally favored at present.

In the West Indian islands the Mexican lime is being propagated on sour orange stock because this stock is deep-rooted and has proved resistant to

uprooting by hurricanes (Freeman, 1930). The Imperial Bureau of Fruit Production (1932, p. 24), referring to the lime in Dominica, stated: "Limes on sour stock have emerged unscathed from disasters of disease and storm that have completely laid low the seedling limes surrounding them. So well have the advantages of the sour stock for limes been demonstrated that the use of the seedling tree has now been entirely discontinued by growers."

Few comparative data on yields of lime trees on different stocks are available. In the orchards of the California Citrus Experiment Station, at Riverside, where only a few trees each of the Mexican lime are being grown on sweet orange, Rough lemon, sour orange, and trifoliate stocks, the comparison of tree size by volume of top and area of cross section of scion trunk shows the following order, from largest to smallest, produced by the various rootstocks: 1, sweet orange; 2, Rough lemon; 3, sour orange; 4, trifoliate orange (Webber, 1932*a*). At fifteen years of age these trees still retained the same comparative size, with little difference between those on the sweet orange and those on the Rough lemon stocks.

On the sour orange stock, the Tahiti, Bearss, and Mexican varieties of limes all show an overgrowth of the scion; with these trees on the trifoliate orange, however, there is a marked overgrowth of the stock. As these reactions indicate a lack of congeniality (see chap. ii, p. 69), and as neither stock gives a very vigorous growth, these two stocks may be eliminated from use with the lime in the United States, unless the sour orange is desired for some special purpose, as for protection from uprooting by hurricanes or against gummosis infection.

From the meager data available it seems that the most promising stocks for the lime, under ordinary favorable conditions, are sweet orange, Rough lemon, and grapefruit. Of these stocks, grapefruit has been used least.

The Florida Experiment Station (Lynch, 1942) reported the results of studies on the influence of rootstocks of Rough lemon, grapefruit, Cleopatra mandarin, bittersweet orange, sour orange, and Willow-Leaf mandarin on the Tahiti or Persian lime. This report indicates: " . . . that fruits grown on rough lemon rootstock were of greatest weight and size throughout the growth period sampled, while fruits grown on the other rootstocks were generally of similar weight and size at any particular age sampled; that there is a general difference in fruit weight and size in different years; that the juice content of the fruit increased with maturity and was similar for the fruit from the different rootstocks at each sampling period; that after the 154- to 156-day age period [after flowering], the juice content became either stationary or decreased slightly; that the percent acid content of the juice was not influenced either by the rootstock or by the age of the fruit as represented in the samples; that soluble solids content of the juice was not influenced by the rootstocks tested."

Sweet orange evidently is the safest rootstock to use for commercial plantings of the Bearss lime in California. Rough lemon may be a desirable stock for the lime under some conditions, especially in gravelly or sandy soils; it is not recommended for use in heavy soils containing many clay particles.

## ROOTSTOCKS FOR OTHER CITRUS SPECIES

*The citron.*—In the citron-producing sections of Italy and Sicily, this fruit is very largely grown from cuttings, but is sometimes propagated on the sour orange. In California and Florida, propagations have been made mainly on sour orange and Rough lemon. On the sour orange, all varieties of citron show a very extreme overgrowth of the scion, and after eight to ten years the trees remain small and sickly in appearance; it is evidently a very uncongenial stock. On Rough lemon the bud also overgrows, but the union is more nearly normal and the trees are vigorous, healthy, and productive. The trees grow very rapidly, the wood is very brittle and, unless supports are used, injury from breakage is severe. Trees growing at the California Citrus Experiment Station from cuttings seem to be in better condition than those on either sour orange or Rough lemon stocks.

Although it is commonly believed that the citron is badly injured by bark and root diseases, Klotz and Fawcett (1930), in their inoculation studies, found the citron to be more resistant to these diseases than the sweet orange, grapefruit, or lemon, but less resistant than the sour orange. The common practice of growing citrons from cuttings in the commercial producing sections of Italy indicates that the species is probably not so susceptible to gummosis as to preclude its extensive cultivation on its own roots. In arid sections, especially on light, well-drained soils, propagation from cuttings would seem most promising.

*The tangelo.*—Tangelos grow well on all the commonly used stocks. The best stocks with respect to influence on size, quality, and texture of fruit have not yet been determined. Probably what has been stated with reference to varieties of the sweet orange will apply also, in general, to the tangelo.

*The kumquat.*—The information available indicates that the best stock for all kumquat species is the trifoliate orange. Although the stock overgrows the scion in this combination, the trees come into fruit early, are fruitful, healthy, and apparently long-lived. On sweet orange stocks the trees grow larger than on trifoliate but are apparently unfruitful. On sour orange stock the growth is slow and unhealthy.

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## Chapter IV

# SELECTION OF ORCHARD SITE

BY

EDWIN R. PARKER

Many factors influence choice of locations for citrus orchards or selection of orchards for purchase. Some of them are general and apply to choice of the wide area in which to plant; others are of local importance within that area. For some regions a single adverse factor may be decisive, but in general the weight given to any one factor or group of factors is relative and depends somewhat upon the degree to which all other requirements are satisfactorily fulfilled. Personal tastes and the element of convenience also play a part. Hence, in the following discussion it should be borne in mind that, within reasonable limits, the degree to which all requirements, real and intangible, are fulfilled should be the basis for decision, but that frequently the relative weight which should be attached to each factor depends in some measure upon the circumstances as they are found.

## CLIMATE

Climate is of the first importance. Beyond certain climatic zones the losses of trees or crops, or the impaired quality of the crops, resulting from adverse weather conditions are so great that the production of all citrus fruits becomes impossible or, at least, unprofitable. In the older, well-established citrus-growing regions enough is known about the weather to permit rough definition of the boundaries of districts that are suitable for large-scale production of the various citrus species. Within these districts, however, there may be local areas where citrus cannot be grown satisfactorily, or where some species may be better adapted than others. Conversely, the climatic factors may be so favorable in rather small areas outside of the larger and better-recognized districts that commercial production of some or all of the citrus fruits is possible in them.

### HAZARDS DUE TO LOW TEMPERATURES

Freezing temperatures are most decisive in limiting citrus production. Unless an area can be obtained for citrus planting where freezes are unknown, it is advisable to choose one—as may be done in many of the commercial citrus-producing areas of the world—where the damage will be infrequent and light. Infrequent frosts or light freezes that injure only the bloom or the crop on the trees are costly though not usually disastrous, but freezes that kill the branches of the trees are serious and result in loss or reduction of the crop for two or more years. Such freezes may lead to permanent ill effects on the trees, particularly if they are repeated at frequent intervals. Freezes yet more severe may kill the trees. Areas where serious freezes are frequent should, obviously, be avoided. However, in many of the established citrus-growing regions, such as those of California, Florida, Texas, Spain, and Italy,

frosts or light freezes occur in occasional years, and in the colder sections of some of these areas freezes infrequently kill or severely injure the woody parts of the trees.

*Minimum temperatures for citrus trees.*—In districts where light freezes occur, limited locations can usually be found where they do little or no damage, or the damage will be so slight and so infrequent that it will be counterbalanced by other, favorable factors. Knowledge of the effects of low temperatures on citrus is essential in choosing a location for planting or in purchasing an established orchard.

*Frost resistance of trees and foliage.*—In a study of climatic effects the relative susceptibility of various species and varieties of citrus to frost injury should be attentively considered. Studies of frost injury in California have shown (Webber *et al.*, 1919; Schoonover, Hodgson, and Young, 1930; Hodgson, 1934; Young, 1940; etc.) that, in winter or spring, temperatures slightly lower than 25° to 26° F. when continued one or more hours generally cause injury to the foliage and small twigs of sweet orange trees, and that at temperatures of 15° to 18° F. the branches of such trees will probably be killed back several feet from their tips. At temperatures of 12° to 15° F. the tree is likely to be killed to the ground. Grapefruit trees are generally considered to be slightly more susceptible to injury than orange trees, and lemon trees are yet more tender. Injury to lemon foliage and twigs will frequently occur at 28° F. if this temperature is maintained for an hour or longer. Lime and citron trees are even more sensitive than lemons, and damage to the foliage of these trees has occurred at temperatures of 30° to 31° F. The foliage and twigs of sour orange and of mandarin trees do not freeze at as high temperatures as those of sweet orange varieties. However, temperatures of 15° to 20° F., if continued long enough, will freeze trees of these species to the ground.

There are slight differences in susceptibility between varieties of any one species. Among sweet orange trees, the Thomson Improved is considered slightly more tender than the Washington Navel orange. Among the lemons, those varieties which produce vigorous growth and dense foliage, such as the Lisbon, are considered slightly more hardy and recover from injury more quickly than lemon trees with sparser foliage, such as most clones[1] of the Eureka variety.

The degree of dormancy of citrus trees influences their susceptibility to freezing. Dormant trees are less injured by the same degree of cold than trees that are actively growing. Thus in areas that are relatively cool throughout the winter, or at least for some time before a frost, the trees usually suffer less injury than in warmer areas in which more continuous growth occurs. Hence, frosts occurring early in the winter before the foliage has matured usually do more damage than those occurring later in the winter. Likewise, spring frosts are more damaging than winter frosts. The presence of a crop on the trees is inclined to maintain the tree in an active condition and to prevent the development of dormancy. Consequently, those varieties which are carrying fruit at the time of minimum temperatures are somewhat more sus-

[1] *For definition of horticultural varieties as clones see Vol. I, pp. 476, 837–838.*

ceptible than those which have no fruit. Thus, Washington Navel orange trees in central California when picked in November or December suffer less injury during a frost in January or February than Valencia oranges which are bearing an immature crop at that time. In Florida, it has been shown that nutritional deficiencies may prevent dormancy and render the trees more susceptible to frost injury. This effect may be the result of reduced numbers of leaves, or a reduction of the rate of carbohydrate synthesis.

It is apparent, then, that the kind of winter in a given area, and its influence on the dormancy of the trees and the time of maturity of fruit, should be considered in the selection of the site and in the choice of the varieties to be grown. In judging the possibilities of any site, reliable records of both the mean minimum temperatures and the absolute minimums from year to year should be taken into account, particularly the occurrence of frosts in the fall before the trees are dormant or in the spring after they have started to grow. (Consult also the subsection, "Influence of Total Effective Temperatures or Available Heat," in Vol. I, p. 60.)

*Susceptibility of fruits and flowers to frost.*—The fruits of citrus trees are usually injured at temperatures that cause damage to the foliage, and under some conditions they may be injured at higher ones. Ripe oranges of the Washington Navel variety have a freezing point of 27° to 28° F. (Schoonover, Hodgson, and Young, 1930); if they are slightly immature, their freezing point is about a degree higher. The freezing point of mature lemon fruits is only slightly higher than that of mature sweet oranges (Gonzales, 1927). Lower temperatures than that of freezing may be endured for a short time without injury because of the lag in fruit temperature as the air temperature falls. The blossoms and young fruits of all citrus varieties are very tender, and temperatures of 30° to 31° F. for a short time may kill them. (See chap. xvii, below.) Although the degree of dormancy of citrus trees modifies the amount of injury sustained in cold weather, the susceptibility of fruits and flowers is apparently little influenced by condition of the tree.

## FACTORS AFFECTING MINIMUM TEMPERATURES

The relationship of certain topographical as well as climatic influences to minimum temperatures may affect the suitability of an entire region for citrus production. They also have great importance locally.

*Elevation and air drainage.*—The temperature of a locality is affected by its actual elevation and by its elevation above adjacent lands. Temperatures decrease 1° F. for each 300 feet of increase in elevation, under ideal conditions. This is the vertical temperature gradient. Particular values are affected by convection currents, radiation from near-by objects. and other objects (Humphreys, 1929; Milham, 1918). Temperatures in the high elevations of mountainous regions and on plateaus are therefore colder, and thus may be less adaptable to citrus. It is reported (Motz, 1942) that some late-maturing oranges are produced in the tropical Petropolis region of Brazil at elevations approximating 2,600 feet. In Southern Rhodesia they are frequently grown at 4,000 to 6,000 feet. However, most of the commercial growing of this crop

is done at relatively low elevations. In the foothills of California nearly all the citrus crop is produced at elevations lower than 2,000 feet. In the citrus regions of India there is a marked adaptability of various species and varieties to the climate at various elevations (Gandhi, 1934). The occurrence either of killing freezes in winter or of frosts in early fall or late spring may limit the growing of citrus at the higher elevations. Frequently, also, elevation has an influence on rainfall and mean temperatures, as well as on absolute minimum temperatures.

The elevation above adjacent lands is often of much more importance locally than the elevation above sea level and is a factor that should always be taken into account in choosing an orchard site. The interpretation of the effect of even slight differences in elevation on minimum temperatures is not complicated. During the night the surface of the earth loses heat by radiation, and the air in contact with it is cooled, becomes denser as it cools, and tends to flow gently to the lowest near-by areas. It is replaced by warmer air from above that has been less affected by contact with the ground surface. This movement is called *air drainage.* (See chap. xvii.)

When unobstructed air drainage is possible, the effect on air temperature at elevated sites on clear, calm nights may be marked even though the actual change in elevation may be slight. A difference in elevation of only 11 feet has been found (Bradford and Cardinell, 1926) to result in a temperature increase of 8° F. In the citrus areas of Florida, increases of 5° F. in temperature for a 10-foot increase in elevation, and of 13° F. for an 88-foot increase, have been reported (Nelson, 1940). The effects of air drainage on temperature as illustrated by Batchelor and West (1915) are perhaps more typical of areas with less uniform topography. These authors show, over a period of time for several stations, an average increase in minimum temperature on calm, clear nights of from 6° to 10° F. with an average increase in elevation of 285 feet. As a result of air drainage, important variations in minimum temperatures, and hence in danger of freezing, occur within short distances even within small orchards, as is illustrated in figure 88. Air drainage is less on cloudy nights, when cooling by radiation from the earth's surface is greatly reduced, than on calm, clear nights; and less, also, on windy nights when the air at various elevations is thoroughly mixed.

Because of air drainage, low pockets in which descending cold air is trapped are ordinarily cold spots. They are often caused by obstructions in valleys, or are formed by hills, rows of high trees, or fills, as in the orchard shown in figure 89. The minimum air temperature in such pockets is, as a rule, appreciably lower than that at only slightly higher elevations where adequate air drainage exists. If the obstruction is large enough, the cold air will accumulate to such a height that the higher lands will themselves be inundated by it.

The interaction of the various effects of elevation on temperatures frequently results in the so-called "thermal belts." Descending cool air is warmed by compression as it nears lower elevations, but at the lowest elevations air that has been markedly cooled by contact with the earth's surface accumulates. The result is the creation of a zone at an intermediate elevation where the

Fig. 88. Effect of air drainage due to variations in elevation on frost injury in a lemon orchard in southern California, 1937. The trees in the foreground were severely frozen, while those in the background were practically undamaged. The injury occurred on a calm, clear night.

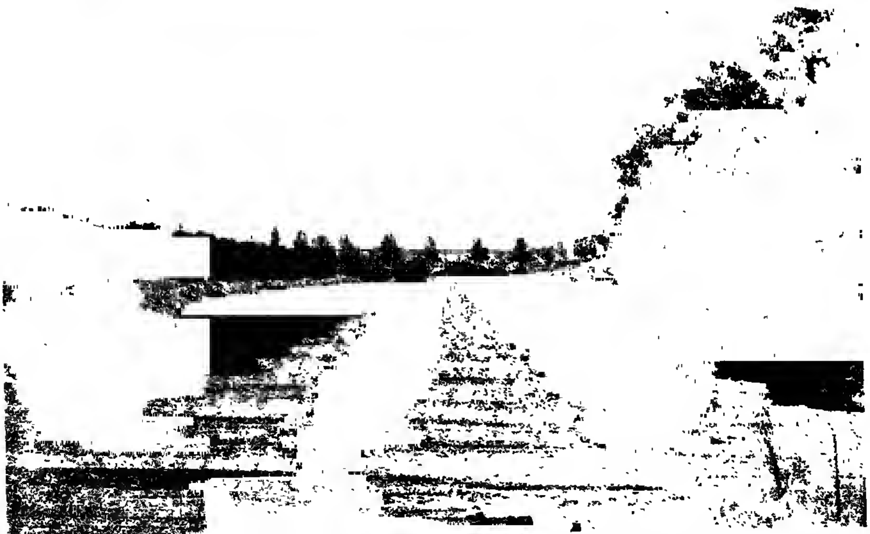

Fig. 89. A low orchard area in which cold air accumulates. It is bounded on two sides by higher land and on one side by a windbreak. The near side is open, but is at the bottom of a gradual grade down which cold air flows. This orchard requires special heating to prevent frost injury.

frost hazard is minimized. Thermal belts are of great importance in the production of citrus fruits; in some regions the only suitable areas are found in them. They are sometimes of great extent, as, for example, the thermal belt on the eastern slopes of the San Joaquin Valley, in California. Although discontinuous, this belt is more than seventy miles long. Its width varies from less than a mile to approximately fifteen miles. Citrus plantings in a narrow part of this zone are shown in figure 90.

*Wind in relation to minimum temperatures.*—Winds have marked effects on temperature, and a study of their effect on the production of citrus in any locality is important.

Under certain circumstances, gentle winds will serve to reduce the frost hazard. If the temperature of the incoming air at a particular place is warmer than that of the air near the earth's surface, the temperature at the ground level will rise. This benefit ordinarily occurs on clear nights when temperature inversion exists (see chap. xvii). Warming also occurs when the incoming air currents have previously passed over near-by bodies of water which warm them. In general, it can be stated that very gentle breezes frequently have the desirable effect of raising minimum temperatures, and that locations where they are prevalent are therefore desirable. On the other hand, locations that are exposed to strong cold winds are not so desirable as protected locations.

The occurrence of north winds at freezing temperatures have markedly limited citrus plantings in the Northern Hemisphere. They introduce great masses of cold air from colder regions and thus lower local temperatures appreciably; they have accompanied most of the severe freezes in the citrus areas of the United States. Locations that are not in their track, or that are protected by natural barriers, such as mountain ranges, are therefore desirable. In southern California, certain large citrus areas are thus protected by the Sierra Nevada and the Sierra Madre. Winds during periods of freezing greatly interfere with orchard heating because they introduce constantly renewed bodies of cold air (Young, 1938) and preclude temperature inversion.

*Exposure.*—Although slopes generally facilitate air drainage, the direction of a particular slope in its relation to exposure to sunlight will usually, but not always, modify minimum temperatures. (See chap. xvii.) However, it may be important as affording protection from freezing winds.

*Bodies of water.*—Where possible, advantage should be taken of the temperature-regulating effect of large bodies of water. These have a great storage capacity for heat, which is released to cold air blowing over them. The moderating effect on air temperature is often appreciable and is of great advantage to orchards situated on the lee side of the water. In California the ocean has this effect in the coastal areas. In Florida and the Gulf States the freezing winds usually blow from the north, and the minimum air temperautres in orchards to the south of lakes are often considerably higher during freezes than those elsewhere. The protection will usually extend a mile or so from the water, or even several miles, particularly if the area of the water surface is large or if the warmed air is trapped by ranges of hills.

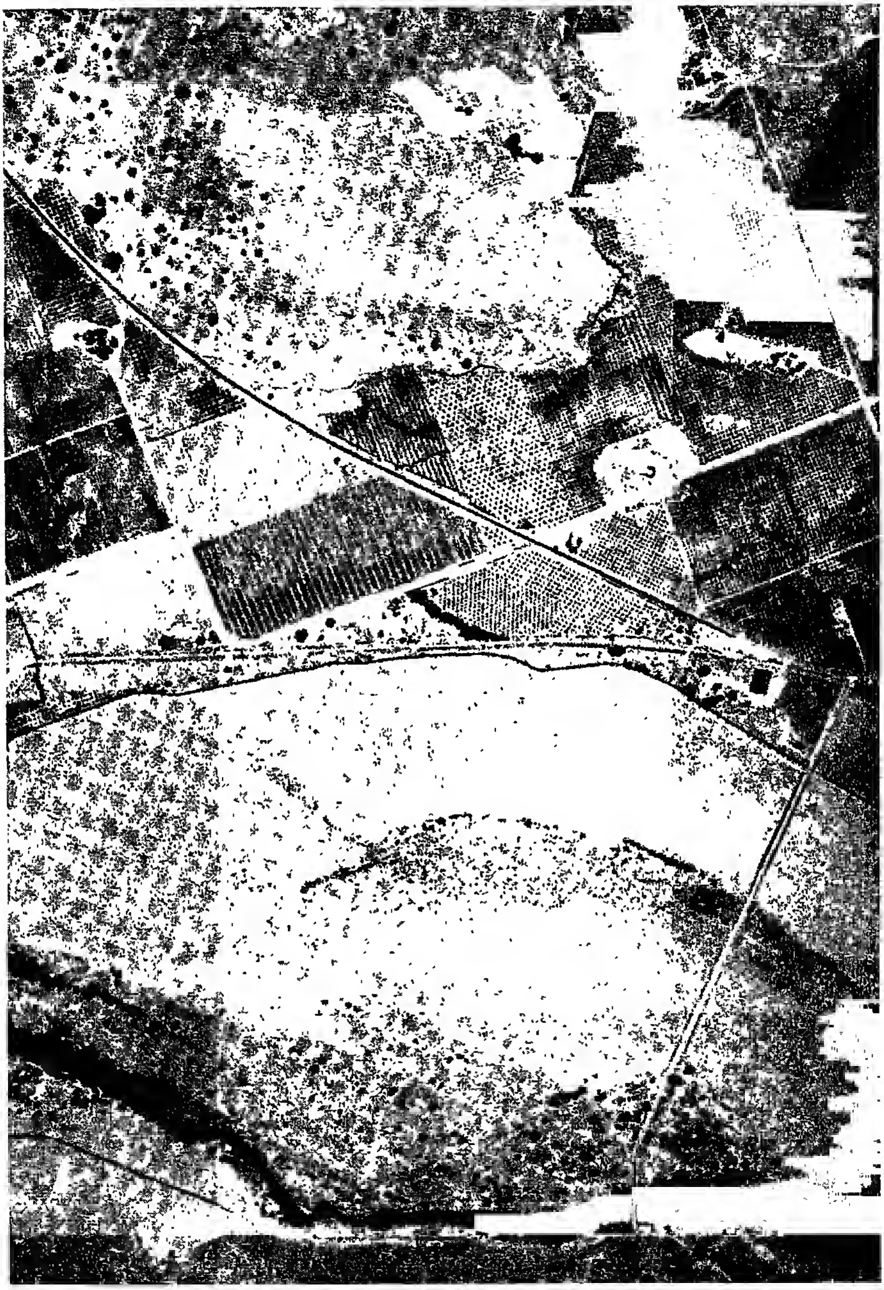

Fig. 90. A small part of the great thermal belt in the central valley of California where citrus trees are grown. The lower lands at the bottom of the view are too cold for these crops. The higher lands are too rough, and at the higher altitudes they are also too cold. (Photograph by Fairchild Aerial Surveys, Inc.)

*Orchard heating in relation to selection of site.*—In regions where heating is feasible, the minimum temperatures, the frequency and duration of the cold periods, and the practicability of raising the temperature with heaters should be considered. The geographical and climatic features which contribute to successful heating are discussed elsewhere (chap. xvii).

The neccssity of orchard heating increases the difficulty of management and the costs of orchard care. Therefore, in choosing a site for a new citrus planting, it appears reasonable that the anticipated average annual increases in costs from heating operations, including interest on the investment in equipment, depreciation, fuel, and labor, should be capitalized at a fair interest rate, and that the amount arrived at be added to the actual costs of developing the orchard. The total will then give a figure which can be compared with similar figures for other heated or unheated sites. This type of computation is also desirable in comparing the values of established orchards which may be open to purchase.

It is frequently observed, at least in California, that areas which are successfully and economically heated may be operated profitably. This is partly owing to the availability of suitable fuels and to the fact that the damage to the crop of unheated or less successfully heated orchards reduces the total supply of citrus fruits, which frequently results in increased fruit prices. Furthermore, other and favorable orchard factors may offset the disadvantages of a moderate amount of orchard heating.

## HIGH TEMPERATURES

Extremely high temperatures are injurious to citrus trees. Although these plants can thrive under quite high average temperature conditions, markedly abrupt increases to extremely high temperatures result in killing of foliage, loss of fruits, and reduction of fruit quality. Young leaves and fruits are particularly susceptible. All kinds of citrus are affected by abrupt and marked increases in temperature, but some are more susceptible than others. Valencia oranges and grapefruit seem more resistant than Washington Navel oranges. The yields of lemon trees appear to be somewhat less severely affected by sudden increases in temperature, possibly because new blooms subsequently occur to replace those lost.

In the fruit-setting period, and until the fruit is about an inch or more in diameter, the normal shedding of young fruits during the "June drop" is increased to abnormal proportions by sudden increases to high maximum temperatures. The effect is more marked if the preceding weather has been cool, and if fruit development has been delayed, as by late blooming. Injury as a result of high temperatures is also greatly increased if the heat is accompanied by desiccating winds, or if the soil is dry.

Before citrus is planted in a new locality, or an orchard is purchased, the frequency of damaging temperatures and hot dry winds should be considered. In the established citrus areas, data relative to the seriousness of these factors can usually be obtained by consultation of public records such as those of the United States Weather Bureau.

### MEAN TEMPERATURES

Within the limits of maximum and minimum temperatures that permit satisfactory citrus growth, some consideration should be given to mean temperatures. Besides influencing the requirements of citrus trees for water, mean temperatures are important in affecting the season of fruit ripening and the quality of the fruit; they will influence the selection of the variety of citrus that should be planted. (Consult also Vol. I, pp. 60–63.) The following examples may be mentioned: In the extreme coastal areas of California, lemon varieties thrive and bear satisfactorily, but Washington Navel oranges cannot be satisfactorily produced. Valencia orange trees grow well, but produce fruit which is below normal in flavor; eight to ten miles farther inland, the mean temperatures are higher and Valencia fruits are normal. Very few Washington Navel oranges are produced even in this interior portion of the coastal section. However, in the hot interior valley sections both Washington Navel and Valencia oranges are grown on a large scale, with production of satisfactory crops of normal fruits. The sizes of citrus fruits are larger in the interior valleys.

Significant effects of differences in the mean temperature are also observed with respect to grapefruit. This species of citrus has a greater heat requirement than oranges or lemons, and insufficient heat results in later maturity and reduced fruit quality. (Compare Vol. I, pp. 73–79.)

### WINDS

Exposure to strong winds is detrimental to citrus trees, and locations where winds are frequently injurious should be avoided. The mechanical effects of such winds are obvious. The fruit is broken off or scarred, resulting in decreased yields and grade, and in increased decay. The loss of foliage sometimes devitalizes the trees, reducing their capacity to set a new crop, and exposes the limbs and fruits to sunburning and frost injury. Winds of hurricane proportions may cause heavy losses of fruit throughout large areas (Anon., 1944*a*). They may split the trees or break off limbs. The trees may even be uprooted if the soil is wet. In the hurricane that swept the West Indies in September, 1928, hundreds of trees were destroyed (Henricksen, 1930). In many areas, winds of lower velocities do damage; hence such areas are less desirable for citrus, particularly if the winds are of frequent occurrence.

Severe damage in some citrus-producing areas is caused by hot winds, especially when the humidity is low (Young, 1926). Such winds, technically called "foehn" winds, frequently have descriptive local names. In the citrus areas of California they are sometimes called "northers" or "easters," and in the Mediterranean regions they are known as "siroccos" or "khamseens." They may actually desiccate the leaves without blowing them from the trees (Reed and Bartholomew, 1930), a kind of injury perhaps more harmful than mechanical defoliation (Brichet, 1942, 1943). The general observation is that use of water by the trees is greatly increased by foehn winds. The existence of other deleterious factors such as excessive quantities of alkali salts in the soil, and of

conditions which restrict the activity of the roots or cause the weakening of the trees (such as the activities of certain pests), will increase the severity of injury done by desiccating winds.

In the coastal areas, cool humid breezes from the ocean are sometimes detrimental to citrus trees. Blanchard (1934) has described a reduction of tree size and yield (Eureka lemon trees) near the coast in Ventura County, California. The winds there are not strong enough to cause mechanical injury to the fruit or leaves.

When harmful winds occur, varying degrees of protection are afforded by windbreaks of tall, dense-foliaged trees placed at an angle to the direction from which such winds customarily blow. In some locations, windbreaks are most desirable. However, certain disadvantages accompany their use. The windbreak trees occupy land that would otherwise be planted to citrus trees, cause some shading of adjacent trees, and interfere somewhat with orchard operations. Their roots compete for moisture and nutrients with the near-by orchard trees; the windbreak rows should ordinarily be irrigated and fertilized to reduce this competition. The roots of windbreak trees, which may extend a distance of four or five trees into the orchard, are sometimes pruned. This is a rather expensive operation and has to be repeated at intervals. It is not always entirely successful, as some deep roots may escape the cutting tools. Extremes of temperature are sometimes accentuated locally by windbreaks as a result of the shade they cast and because of their interference with normal air movement. Although their net effect may be profitable in a particular orchard, it is evident that the use of windbreaks is not an unalloyed blessing.

## RELATIVE HUMIDITY

The desiccating effect of winds under conditions of very low humidity has been mentioned. There may be some drying of the foliage and loss of crop when the humidity is very low and even though the wind is not excessive, especially if there has just been a period of high humidity. At such times the growth of trees and of fruit is temporarily checked. Abrupt decreases in relative humidity to a very low percentage are therefore considered detrimental.

The requirements of the trees for soil moisture are greatly affected by relative humidity. The quantity of irrigation water needed, and the methods of irrigation, are influenced by differences in this climatic factor.

Humidity also regulates the incidence and importance of certain pests and diseases of citrus trees and fruits and is an important factor governing the distribution of some of them. The conditions of atmospheric humidity do not, however, affect all diseases and pests alike, since some seem to be favored by arid and others by humid conditions. As a result, citrus culture is practiced commercially in regions of both high and low humidity. However, regions in which the fluctuations in humidity are not excessive are considered the more favorable.

## RAINFALL

In many citrus regions of the world the amount and annual distribution of rainfall are such as to supply a sufficiency of water for the trees at all seasons.

In semiarid citrus regions the rainfall commonly averages from five to twenty inches, not enough for the needs of citrus trees in those areas. Moreover, the rains may occur at seasons when the water requirements of the trees are least. Citrus soils in such areas must therefore be watered by artificial means. Attention should be given to the seasonal distribution of rainfall in judging its effectiveness. Some places, such as Ceylon, may require irrigation at some seasons although the total annual rainfall may be as much as sixty inches (Parsons, 1932). In Florida, where the rainfall approaches this amount, most of the rainfall occurs in the summer months, and in some years the amount that falls in winter and spring is insufficient.

When considering the planting of an orchard, or the purchase of one which has been planted, it is prudent to estimate both the water requirements of the trees and the losses of water from the soil in any particular area. (For the factors that affect the amount of water required for raising citrus trees, see chap. x.) This study should be carried out for each season of the year. The average total rainfall and its seasonal distribution should then be determined and set opposite the data for water requirements. Variations in rainfall from year to year should be considered. A comparison of the two sets of figures will indicate whether irrigation is necessary and at what season. The experience of growers of citrus, and of other crops in the vicinity, is also of value in determining the probable water requirements and in making provisions for meeting them.

An analysis similar to the foregoing should also indicate whether excessive amounts of rainfall occur that might be unfavorable for tree health or an inconvenience in orchard operations. The health of the trees is likely to be affected by soils in which percolation is slow or where water tables may develop within the root zone. Such conditions can seriously affect the crop (see below).

## SOILS FOR CITRUS TREES

The soil requirements of citrus trees, like those of other fruit trees (Chandler, 1925, 1942; Gardner, Bradford, and Hooker, 1939), are in some respects more exacting than those of annual crops. Soils that support satisfactory or even excellent growth of annual crops may be entirely unsuited for good growth of citrus. The chemical constitution of the soil may be unfavorable. It is the physical characteristics of the soil, however, that generally are of more importance. The researches of Cannon (1925) and of Girton (1927) have demonstrated that citrus roots have a rather high requirement of oxygen. Other studies indicate that a supply of available oxygen in the soil is necessary for the metabolic processes of plant roots and for the absorption of water and nutrients. Available oxygen also favors the presence of a beneficial soil flora. Physical conditions that permit adequate aeration of the soil in the root zone are therefore essential.

It has been generally observed that the lateral spread of the roots of citrus trees is greater than the spread of the branches. Mills (1902) found that the roots of a nine-year-old orange tree extended 18 feet from the trunk. Older trees have been found with roots more than 22 feet from the trunk. The

majority of the roots are generally found in the top 3 feet of soil, with the greater concentration in the top 2 feet. Studies of the amount of water removed from soil by roots indicate that root activity is also greater in the upper soil horizons, but that some water is removed from lower depths. The root systems of citrus trees, like those of other fruit trees (Chandler, 1925, 1942; Rogers and Vyvyan, 1934), are ordinarily more extensive in light soils than in heavy soils; in light soils occasional roots have been found at depths below 15 feet.

Inferior growth of citrus trees may result from unfavorable conditions in the entire root zone, or only in part of it. The effects of poor aeration, with consequent impaired functioning of roots, in the lower depths of the root zone are not usually evident until the trees are fairly large, or until heavy rainfall or excessive irrigation displaces an undue proportion of the oxygen in the pore spaces of the soil. Favorable aeration throughout the entire root zone is therefore desirable. It is also important that favorable soil conditions be permanently maintained, since temporary unfavorable periods, such as those brought about by the flooding of soils, may result in damage or even death of the trees.

## PHYSICAL CHARACTERISTICS OF SOILS

Attention has been directed to the importance of the physical nature of soils as affecting aeration and the depth of rooting. The physical characteristics are determined by the size of the soil particles (texture), the positional relation of these unit particles to one another (structure) in the various strata or horizons of soil, and the relations of the strata to one another (profile characteristics). These factors determine the total pore space and the size of the pore spaces through which water and air must move in the soil. They thus regulate the rate of drainage of free water throughout the soil mass.

*Drainage and depth of soil.*—No single characteristic of good citrus soil is more essential than good drainage. Without satisfactory drainage, accumulations of free water in the root zone result in a lack of aeration and injury to the roots, followed by a consequent reduction in root activity and possible toxicity. The roots may be rendered more susceptible to infection. Lack of drainage results in undesirable chemical changes in the soil and in the increase and activity of harmful soil organisms. These effects may lower the vigor of the trees or even cause their death. Damage may result from a single flooding of the root zone. Experience in Florida (Hume, 1934; Scott, 1928; Vosbury and Robinson, 1929), Texas (Friend, 1933; Hidinger, 1911; Parkes, 1932; Potts, 1924), Ceylon (Parsons, 1932), South Africa (Powell, 1930), and other regions, emphasizes the value of deep, well-drained soils for citrus culture. Shallow soils with impervious subsoils which restrict the root distribution of the trees and in which free water accumulates should therefore be avoided. Even in semiarid regions, occasional rainstorms, lateral seepage, or unwise irrigation can cause accumulation. In regions of heavy rainfall the use of shallow soils of this type is particularly hazardous. A soil which is not suitable for citrus growing is shown in figure 91. Here, a shallow clay surface soil overlies a cemented sandstone substratum. Exceptions do exist, as near the coasts of Florida, where excellent orchards grow above water tables that are rather

constantly maintained at two or three feet below the surface; but special procedures in orchard management are then necessary. In semiarid regions there are rare orchards growing on slightly less than three feet of good soil. These conditions are hazardous, however, and imply rapid lateral movement of water in the soil to a near-by point of removal, or fractures in the subsoil that permit drainage. Carefully controlled cultural practices are advisable for shallow soils; the installation of drainage ditches or tile drains may be necessary. Low areas where water accumulates as a result of surface or subsurface drainage are almost always unsuited to citrus production, because of the probability that high water tables will periodically develop. In figure 92 is shown an example of the harmful effect on lemon trees of the lateral movement and accumulation of water upon an impervious subsoil. Here, an impervious stratum exists about two and one-half feet below the surface. Water movement of this type may extend for some distance. Its probability can usually be established before the orchard is planted. Examinations made in the rainy season are most likely to be helpful.

In residual soils the depth of soil that is satisfactory for the growth of citrus roots may be limited by the presence of the parent rock from which the soil was formed. In old alluvial soils the presence of a cemented stratum may have the same effect. Such areas of shallow soils should be planted to orchards only after thorough examination. Areas where the limiting material is not decomposed or fissured to such a degree as to permit adequate water movement through it should not be used. Occasionally, hardpan layers may be thin enough to permit partial destruction by blasting with dynamite when the soil is dry. Preliminary examination and tests should indicate whether blasting would be effective.

Since the effects of free water within the root zone are so serious, the possible existence or formation of a water table should be studied in most lands, even in those which have a definite slope, and especially if the location is at about the same elevation as that of near-by bodies of water. Irrigation and drainage ditches that are not waterproofed sometimes create water tables in the lands near them. If water tables are found, it is sometimes possible to intercept the flow creating them, or to lower them by drainage with open ditches or by tile drainage, provided adequate outlets can be obtained. Perched water tables are occasionally formed when a fine soil overlies a soil of very coarse texture and when the line of contact between the two is sharply defined.

*Types of soil.*—Soils possessing a rather uniform profile within the normal root zone are usually the most satisfactory for citrus-tree performance since water movement is not impeded in them by variations in texture. Root development is also more uniform in them. Uniformity of soil throughout the orchard greatly facilitates cultural operations, particularly irrigation.

Soils of very coarse texture are sometimes to be avoided; they are commonly low in organic matter and hence in native fertility. Furthermore, coarse soils leach readily and require a carefully regulated fertilizer program. Their low moisture-holding capacity may also be objectionable, particularly if rainfall is sporadic or where frequent irrigation is not practical. However, the effi-

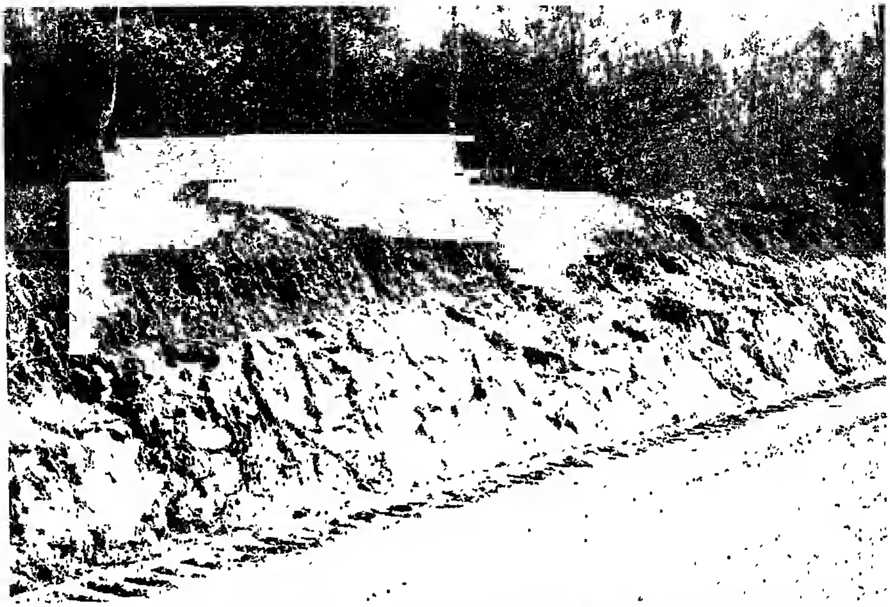

Fig. 91. Cross section of a clay soil unsuitable for growing citrus trees. The surface soil is compact and movement of free water through it is slow. The subsoil consists of sandstone and resists water penetration. For some time after rains, water may be observed seeping from this soil at the point of contact between the clay and the sandstone, about eighteen inches from the surface of the soil.

Fig. 92. Serious damage to lemon trees resulting from excessive amounts of water in the soil, which have accumulated as a result of seepage from a higher elevation upon an impervious subsoil. The subsoil consists of dense parent-rock material and is about two and one-half feet below the surface.

ciency of irrigation will probably be low, owing to rapid percolation of water below the root zone, and frequent applications of water will be necessary.

Conversely, there are serious objections to clay soils. The aeration of such soils is poor, owing to the small size of pores in them, and the roots may suffer for lack of oxygen. Root distribution in these soils is usually restricted, and trees may never reach normal size. The cultivation of clay soils is difficult and must be carefully carried out in accordance with the characteristics of the soil and its moisture content (Surr and Batchelor, 1926). Further problems of soil moisture may arise as a result of the high moisture-holding capacity and slow drying out of such soils. The wet condition of the soil over prolonged

TABLE 19

Average Yields of Orange Trees on Different Soil Types (After Vaile, 1924)

| Type | Yield in lbs. per acre by climatic zones | | |
|---|---|---|---|
| | Coastal | Intermediate | Interior |
| Sand—very light | 14,400 | 13,700 | 11,400 |
| Gravelly sandy loam and sandy loam—light | 20,100 | 19,200 | 16,000 |
| Fine sandy loam—medium | 21,200 | 20,100 | 16,700 |
| Loam—heavy | 19,600 | 18,700 | 15,500 |
| Clay loam—very heavy | 19,000 | 17,900 | 14,900 |

periods greatly increases the chances of infection with gummosis and root-rot diseases of the trunks and roots, and special attention must be given to methods of irrigation and to treatments designed to minimize this influence. The use of disease-resistant rootstocks is ordinarily important in heavy soils.

The clay soils that crack upon drying (the adobes) present special problems in handling. In these soils of very high water-holding capacity, cultivation and the regulation of soil moisture by irrigation are critical operations. The usual practice in California is to allow the soil to crack before irrigation, thus permitting a periodic aeration of the lower depths as well as a satisfactory penetration of water. The difficulty of controlling water movement, and the limited root distribution which occurs in such soils, further complicate their management. Many adobe soils produce only small or moderate crops of citrus fruits and could more profitably be applied to other uses.

Between the very light soils at one extreme and the heavy clay and adobe soils at the other, there are a great number of soil types that are satisfactory for the production of citrus trees. This is well illustrated by the results of the extensive survey of factors affecting yields of irrigated orange trees in three climatic zones of California conducted by Vaile (1924), which are presented in table 19. The results indicate that the yields in each climatic zone are almost equal in the three soil types—light, medium, and heavy. Reductions in yield resulted, however, when trees were grown on very light or on clay soils. Similar results were obtained in a survey of a more limited area by Parker, Rounds, and Cree (1943).

## CHEMICAL CHARACTERISTICS OF SOILS

*Fertility.*—The fertility of citrus soils appears, within limits, to be less important than the physical characteristics just discussed. In this respect citrus trees do not differ from deciduous fruit trees (Oskamp and Batjer, 1933). Yet, if drainage and other physical factors are equal, a naturally fertile soil has a great advantage over an infertile one, and is to be preferred. Fundamental differences in the fertility of soils used in citrus culture exist under different climatic conditions and are affected by previous use of the land. Fertility experiments indicate that the fertilizer program should be adapted to the local conditions. Information on effective methods of fertilization in the various citrus areas of the world is gradually accumulating. (See chap. vii.) Unfortunately, no chemical methods are available by which the relative fertility of closely similar soils can be determined exactly. Application of the results of chemical analysis may nevertheless be valuable: an analysis may indicate ample amounts of certain nutrients or harmful concentrations of various elements or salts.

Much can be learned of the fertility of a soil by observing the type and vigor of growth on it of native or cultivated trees and shrubs. Where these are luxuriant, the probabilities of a satisfactory fertility level are good, although some knowledge of the types of soils favored by particular groups of plants may be desirable.

*Soil reaction and nutritional deficiencies.*—Within rather wide limits the acid or alkaline reaction of the soil, as indicated on the pH scale, is not *of itself* a very important factor in California citrus growing. Satisfactory crops are produced on various soils ranging from about pH 5 (very acid) to about pH 8.5 (very alkaline). On many soils the adjustment of pH by the addition of agricultural minerals (soil amendments) within this range has not affected the trees (see chap vii). However, in some soils, as for example the sandy soils of Florida, which have very low base-exchange capacities, the availability of plant nutrients varies with their reaction. Camp (1943), Peech (1941), and Jamison (1942) indicate that in those soils pH values between 5.5 and 6.0 are the most favorable. They find that lower values (greater acidity) increase the solubility and leaching of calcium, magnesium, and other bases and that higher values (less acidity) decrease the availability of the minor elements. In the soils they mention, the desired pH is readily obtained by the application of certain minerals such as dolomitic limestone and acid-forming fertilizers (Camp, 1939). Adjustment is more difficult and now appears to be of less importance in most citrus soils.

In many soils, moderately alkaline reactions (pH 7.0 to about 8.3) apparently decrease the solubility of certain plant nutrients in water (Allison, 1931; Chapman, 1934) but may not decrease their availability to plants. However, high alkalinity, at pH values of 8.5 or greater, usually indicates the presence of excessive amounts of sodium salts. Soils containing from 2 to 4 per cent, or more, of lime (calcium carbonate) may also have a pH of 8.5. In such highly alkaline soils the availability of the minor elements may be greatly decreased,

and symptoms of their deficiency may develop. Among these, iron deficiency is the most difficult to correct. In many locations, lime-induced chlorosis resulting from iron deficiency is a limiting factor in citrus production.

The growth of annual plants is rarely a good indicator of high lime concentrations or the availability to citrus trees of the minor elements. Sometimes the application of a dilute acid, such as lemon juice, to a sample of soil indicates

Fig. 93. A shallow, heavy soil underlain by limestone. This soil has a high moisture-holding capacity and is quite alkaline. Iron-deficiency symptoms develop on citrus trees grown on it.

by effervescence (the evolution of carbon dioxide gas) the presence of large quantities of carbonates. Examination of the soil, particularly of the subsoil, for the presence of strata or local areas which are rich in lime is desirable. Figure 93 illustrates a soil having a marked stratum of limestone close to the surface. Such a soil, highly alkaline and deficient in iron, is entirely unadapted to the growing of citrus trees.

Symptoms of the deficiency of the minor elements, especially zinc, copper, and manganese, occur in acid as well as in alkaline soils (Camp, Chapman, Bahrt, and Parker, 1941). Methods of correction are, however, available and hence these deficiencies are not now regarded so seriously as heretofore (Coit, 1915).

*Toxicity due to alkalinity and salinity.*—Citrus trees are particularly sensitive to high concentrations of salt (see Vol. I, p. 757), and soils which contain them should usually be avoided. Such soils commonly contain excessive amounts of sodium (these are the "black alkali" or "alkali" soils), or of the chlorides or sulfates of calcium and magnesium (the "white alkali" or "saline" soils). With rare exceptions, as where lands of humid regions are invaded by sea water, harmful concentrations of salt constitute a problem of arid or semiarid regions. Salts seldom accumulate as a result of the weathering of soil particles in place. They are generally concentrated by evaporation from ground water tables or from ponded surface water. Irrigation water is a very common source of salt (see below). Failure to obtain leaching, owing to insufficient rainfall, unfavorable irrigation practices, or—most commonly—to poor drainage, ultimately results in accumulations. The importance of satisfactory soil permeability and of the absence of a high water table, both of which factors are essential for adequate soil drainage, cannot be too strongly emphasized (Hayward and Magistad, 1946).

The harmful effects of salt concentrations may be attributed, in part, to increased osmotic concentration of the soil solution—an effect which reduces the ability of plants to extract water from the soil. The degree of salinization which contributes to this effect can be estimated by laboratory methods (Richards *et al.*, 1947). The various salts and their ions differ, however, in their specific effects (see Vol. I, chap. vii). Boron is very toxic in relatively low concentrations. Chlorides are also more toxic than many salts, and chloride injury is observed in parts of many irrigated regions. Special consideration should be given to sodium because of its relation to the formation of black alkali and to the permeability of the soil. When the clay fraction of a nonsaline soil has adsorbed an unduly large proportion of sodium and the proportion of adsorbed calcium and magnesium is correspondingly low (all values being expressed in terms of the total exchangeable bases), the soil structure deteriorates and the permeability of the soil is reduced, if not destroyed. Affected soils are frequently dark in color and have pH values between 8.5 and 10.

Careful inspection of the soil, the native vegetation, or the cultivated crops will frequently indicate the presence of excessive quantities of salts. Chemical analyses of the soil and of the irrigation water are more reliable, however, and should be made in all doubtful cases. Analyses of citrus leaves sometimes provide information.

Salty soils can be reclaimed under certain conditions (Kelley and Brown, 1934; Richards *et al.*, 1947) if soil drainage is adequate. Reclamation, and loss of use of the land, may, however, prove costly. The most efficient reclamation requires the technical knowledge of the drainage engineer and the assistance of the soil chemist.

## PLANTS AS INDICATORS OF SOIL ADAPTATION

In areas where citrus trees are growing, the vigor and productivity of the orchards provides perhaps the best index of soil conditions. The condition,

production, and longevity of trees should be determined. Examination should be made for characteristic symptoms of nutritional deficiences or excesses.

However, rather close correlations often exist between the types of native plants on certain soils and the adaptability of those soils for citrus. In Tulare County, California, live oak trees (*Quercus agrifolia*) do not grow on the soils derived from certain types of basic igneous rocks. Such soils are predominantly very heavy, poorly aerated, and are not well adapted for citrus growing. However, native oaks grow abundantly on the soils derived from granitic sources, which have better physical characteristics and produce excellent citrus trees.

In Florida, citrus soils have long been selected on the basis of the native growth (see Vol. I, p. 80). The classifications of Hume (1934) and of Peech (1939) are particularly valuable as indicators of the drainage characteristics of fertility levels of the virgin soils of that state.

## TOPOGRAPHY AND SOIL UNIFORMITY

The topography of the land used for citrus culture is of importance in orchard management as well as in its effect on air temperatures. Where the land is steep its susceptibility to erosion will probably be excessive. As the surface soil is best adapted to the growing of plants because of its greater fertility and usually better physical condition, its removal by erosion is detrimental. The selection of level lands or lands with only gentle and uniform slopes is desirable. If the slope of the land indicates that erosion is likely to be troublesome, the tree rows should be planted on the contour, or possibly planting on terraces will be necessary. Figure 94 illustrates one effect of erosion in a lemon orchard. The removal of moderate quantities of surface soil and the deposition of large amounts of alluvium about others is clearly evident. The topography will also affect the selection of an irrigation system, and may require the installation of pipe lines or permanent ditches to carry away the runoff water resulting from rains or irrigation.

The possibility of flood damage by overflow of water from adjacent lands and highways should also be taken into account; many orchards have suffered serious damage from this cause. Information on rainfall characteristics should be obtained, especially the occurrence of exceptionally heavy storms, and natural drainage channels should be located.

An example of an orchard site selected with foresight and carefully planted so as to take advantage of natural drainage channels is shown in figure 95. The channels divert floodwaters which arise outside the orchard area, and also carry away those surface waters which collect in the orchard itself. The orchard is planted along contour lines where the slope of the land made this plan of planting desirable. Even when irrigated land is not so steep as to require contour planting, it is desirable to divide it into blocks in which the irrigated rows have a desirable slope, irrespective of directions, as illustrated in figure 96.

Surface soils and subsoils should be carefully investigated before planting is begun, to determine whether they are satisfactory in type, depth, and opportunities for drainage of excess water. Soils that are not reasonably uniform

Fig. 94. Effects of erosion within a lemon orchard of variable topography. *Top view:* several inches of surface soil have been removed, leaving the bud unions high above the soil surface. *Bottom view:* trees partly buried by the deposition of soil removed from the higher and steeper parts of the orchard. (Photographed by Mauriee Donnelly.)

within an area selected for planting complicate orchard plans and operations, particularly if the variations are pronounced within small blocks. Extreme variation in soils results in trees that are markedly variable, as is shown in figure 97. Here, very sandy areas traverse several small orchards, and result in small trees and low yields because the management practices cannot be adapted to all the soil conditions. The nature of the soil in high and low spots should be considered carefully in relation to cultural operations. Soil augers,

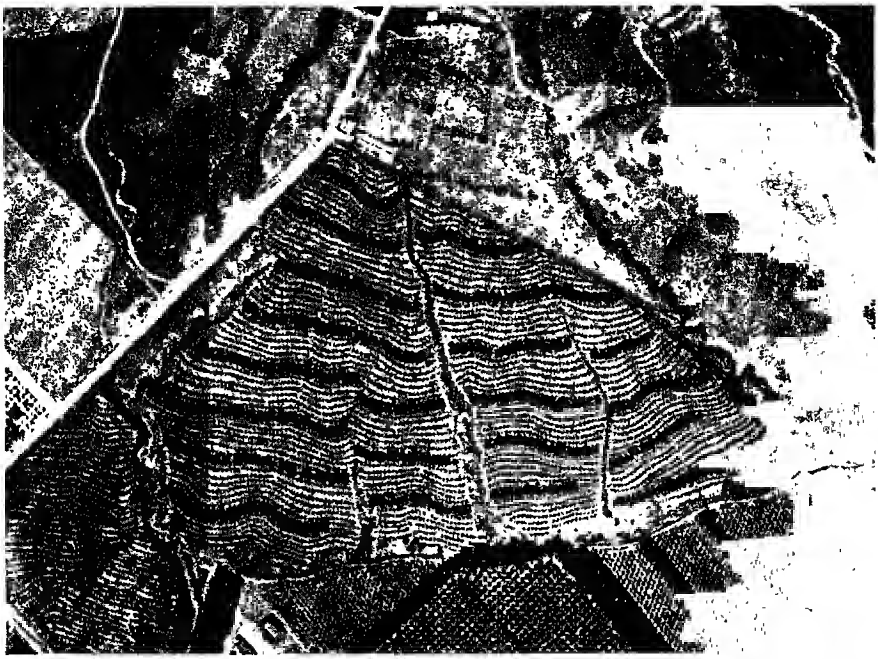

Fig. 95. Orchards well protected against erosion. Drainage ditches adjacent to and within the orchard and the contouring of the planting minimize danger of erosion within the orchard. Windbreaks reduce damage by strong winds. (Photograph by Fairchild Aerial Surveys, Inc.)

soil tubes, or shovels are needed for making the examinations, which should extend to depths below the penetration of most of the citrus-tree roots. Deep cuts in the soil, made at some prior time for railways, highways, pipe lines, or similar purposes, help to show the soil profile.

These procedures not only aid in the selection of locations satisfactory for planting, but frequently give much information on the most successful methods of planting and management. Detailed examination of the soil assists greatly in determining the adaptability of the land for irrigation and the necessities of laying pipe lines. All these factors influence the cost of development and maintenance of an orchard, as well as its satisfactory performance, and it is important to have definite information about them in advance.

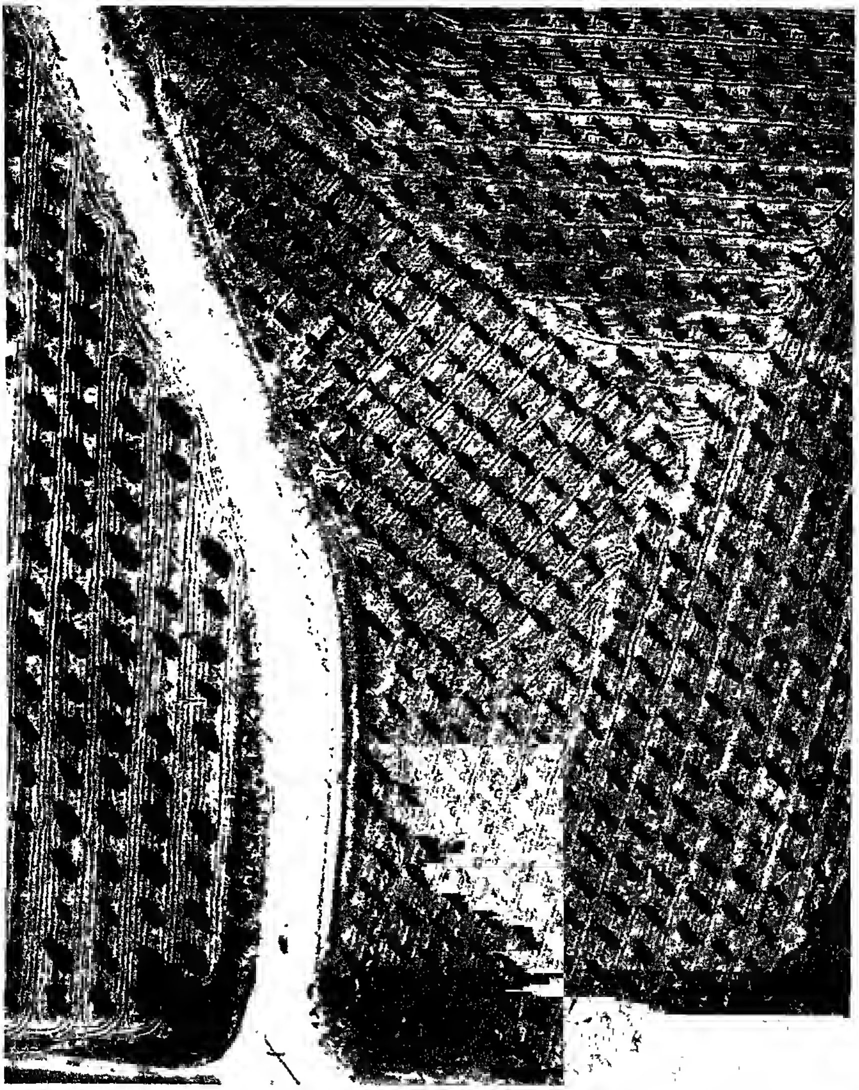

Fig. 96. Orange orchard planted on land sloping gently in several directions. (Photograph by Fairchild Aerial Surveys, Inc.)

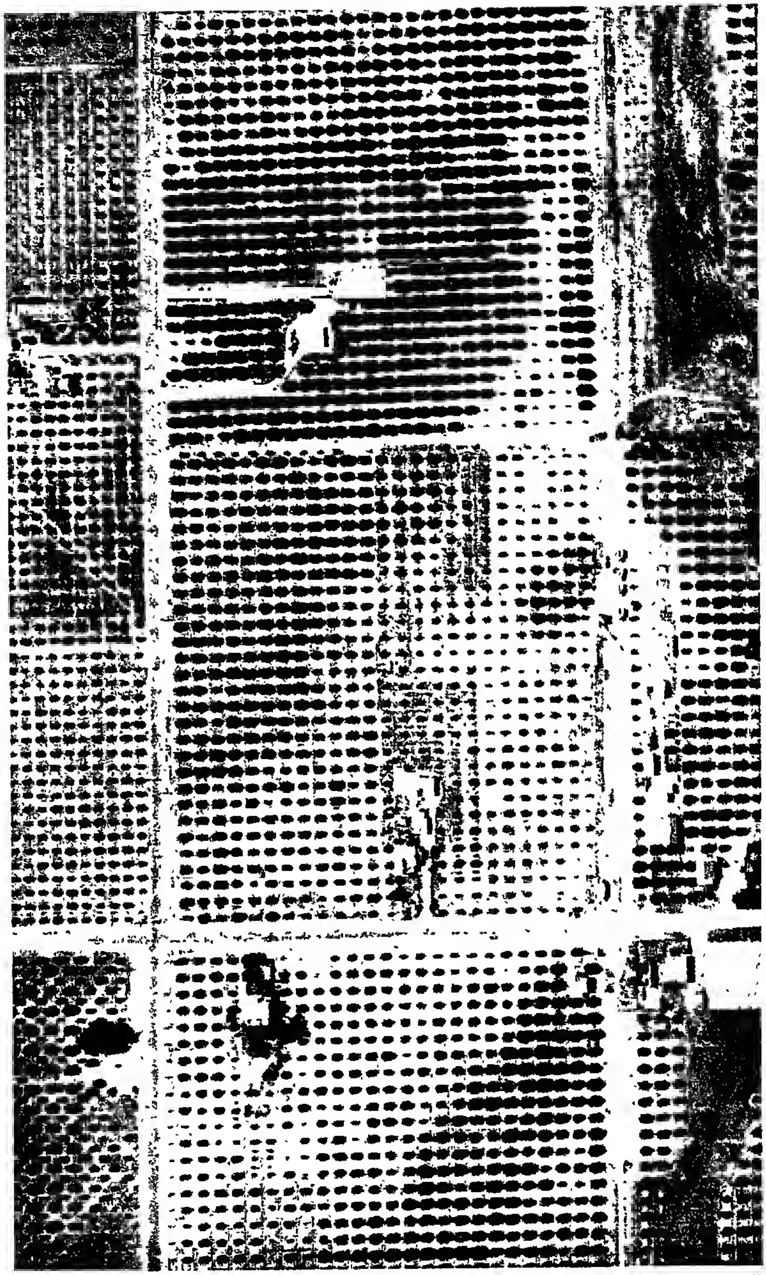

Fig. 97. Variations in size of orange trees due to strips of very sandy soil which traverse several orchards. The larger trees are on sandy loam soil. The change in soil type has made satisfactory irrigation of all areas very difficult. (Photograph by Fairchild Aerial Surveys, Inc.)

### OBTAINING INFORMATION ON SOILS

The importance of soil factors for successful production of citrus trees indicates the advisability of obtaining reliable information on soil conditions before a site for an orchard is finally selected. In the United States, the agricultural literature of the state, and the soil maps of the region, should be examined. The soil maps are prepared by government agencies and contain much valuable general, and often specific, information about the characteristics of soils. The literature on this subject is usually available in public libraries and through the agencies of departments of agriculture and of universities. The Farm Advisors or County Agricultural Agents should also be consulted on the characteristics of various local soil types and their adaptability to citrus growing. The usefulness of soil surveys and personal inspection in judging the value of land for future planting can sometimes be more clearly established by the use of an index which integrates the physical and chemical properties of a soil so far as they affect the growth of agricultural crops. An example of such an index has been prepared by Storie (1933), and has been extended to large areas of California by Weir and Storie (1936). The judgment of farmers and of officials of farmer organizations who have had experience with various soil types in the region should also be sought.

## PROBLEMS OF IRRIGATED AREAS

In citrus regions of deficient rainfall a sufficient supply of water of satisfactory quality is necessary to supplement the normal precipitation. This water supply must either be developed on the property or delivered to it by appropriate pipe lines or canals. Several problems at once suggest themselves for consideration.

### ADAPTABILITY OF ORCHARD SITE TO IRRIGATION

The future orchard must possess such characteristics as will permit it to be irrigated successfully. The importance of various soil characteristics in this respect has been discussed above. These determine the ease of the penetration and movement of water in the soil, as well as the soil's retentiveness of water. The relations of the topography of the land to the method of irrigation, and hence the planting plan of the orchard, have been discussed briefly. Additional comments are given in chapter v.

### WATER FOR IRRIGATION

Wells and surface streams are the two common sources of water for irrigation. In many of the arid regions the flow of streams is seasonal, and it is necessary to impound stream water in surface or subterranean reservoirs in order to conserve the supply and to have the water available when needed. Long pipe lines or ditches may be necessary to deliver water to the place where it is to be used, and many farms may be served by one water system. For these reasons the development of irrigation water is often undertaken by associations or corporations, which are usually regulated by law.

The supply of irrigation water in many regions is insufficient to supply all the land that might be irrigated, and its value is therefore high. The gradual increase in demands for water has frequently resulted in complicated legal situations. It is important that the legal right to use an adequate amount of irrigation water should be established at the time of selecting an orchard location, in order to avoid risks of loss or litigation in later years.

*Quantity of water.*—The supply of water should be adequate for all immediate and future needs of the citrus trees and for any intercrops that may be grown with them. The total demand upon the irrigation system should be worked out in advance, and an estimate should be made of the supply of water available to meet such demands in future years.

The water requirements of mature citrus trees are influenced by temperature, wind, and humidity. Variations in these factors may result in important differences in districts not far distant from one another. In the coastal zones of California the annual irrigation requirement is customarily 10 to 12 acre inches. In the zone about forty miles inland the requirement is 30 to 40 acre inches. The amount of water lost by surface runoff and deep percolation varies with topography and soil type, the nature of the irrigation system used, and the efficiency of the individual irrigator. The moisture-holding capacity of the soil, the age of trees, the density of planting, and the growing of intercrops are also factors of importance (see chap. x).

The varying requirements for irrigation water in different seasons of the year are marked, and the grower should make certain that the irrigation system is adequate for supplying the peak demand.

*Quality of irrigation water.*—Wherever irrigation is practiced, the quality of the water is of the utmost importance. Use of waters containing an appreciable quantity of salts may result in accumulations in the soil that reduce the yield of citrus trees (see Vol. I, pp. 757–762). Nevertheless, no definite limiting concentration of salts in irrigation waters can be established that will apply to all situations. It depends upon the nature of the salts and the resulting balance reached between the quantity of salts applied and the quantity lost by leaching, as well as the climate and the susceptibility of the type of citrus grown. Grapefruit trees are usually more tolerant than orange trees, and the latter are more resistant to high salts than lemon trees (Kelley and Thomas, 1920). The climate determines the amounts of water used by trees and cover crops and the losses by evaporation from the soil, as well as the rainfall, and hence the quantity of irrigation water which must be applied. The quantity of irrigation water used, as well as its quality, regulates the amount of salts applied. Leaching is favored by permeable soil, absence of a free water table, good distribution of an adequate quantity of irrigation water, and especially by the annual amount and distribution of rainfall, which is the most effective leaching medium.

Salts containing harmful amounts of sodium and chloride are most frequently found. Concentrations of chloride greater than 150 to 200 p.p.m. may generally be regarded as excessive. Lower values may be dangerous if the soil is poorly drained. Large proportions of sodium are especially harmful

in soil and irrigation water. Excess quantities of this element tend to deflocculate the soil and decrease its permeability. Irrigation waters containing more sodium than the sum of calcium plus magnesium (the so-called "soft" waters) are considered potentially more harmful than those in which the sodium is in less quantity than the sum of calcium plus magnesium (the "hard" waters), especially if the soil normally contains much sodium and is low in calcium (Kelley and Brown, 1934). Ratios of sodium to calcium plus magnesium in the irrigation water greater than 2 to 1 may be expected to result in an accumulation of sodium in the soil (Kelley, 1940).

Other elements may occur in toxic concentrations in irrigation waters. Boron is one of the more important (Kelley and Brown, 1928; Eaton, 1935*a*). Concentrations of boron as low as 0.5 p.p.m. may cause severe injury to all citrus (Kelley, 1940; Eaton, 1935*b*); lemon trees may be injured by water containing 0.3 to 0.4 p.p.m. Orange and grapefruit trees are slightly more tolerant. Since boron may accumulate in soils over a period of years, especially if soil drainage is impaired, it would be prudent to regard with suspicion any concentrations of boron greater than 0.25 p.p.m. in irrigation water.

The chemical analysis of irrigation water is valuable in determining its suitability, since by this means the presence of harmful concentrations of the elements can be determined. Practical experience in a specific area and the observation of results obtained in existing orchards provide the best background for estimating the suitability of waters of different analysis.

### COST OF IRRIGATION WATER

The costs of water for irrigating citrus trees vary greatly. In established citrus-growing regions, such as California, where irrigation is practiced, water is most frequently obtained through membership in a company or association which provides and distributes it to the members' properties. Membership entitles the holder to a legal right to the use of a certain amount of water or a certain proportion of the total amount available. The market value of the stock of such companies fluctuates, varying from about $10 to $350 or more per acre. Investment in a water right of this kind should be regarded in the same manner as the investment in the land. In fact, the two should be considered together.

In addition to the capital investment in the water right, annual charges may be expected for a proportionate share of the maintenance, depreciation, and other costs of the water company. Wallschlaeger (1935) reported that the average annual cost for water to California citrus growers in 1934 was $24.71 per acre for oranges and $37.71 for lemons. In 1942, after a period of more copious rainfall, average costs of $18.44 for oranges and $20.22 for lemons were reported (Anon., 1944*b*). Unit costs of water vary greatly. Thus Blaney and Huberty (1930) showed that in 1929 an acre-foot of water, when obtained from nonprofit companies serving citrus areas in California, ranged in cost from $2.98 to $41.27, including interest on the investment. Although the highest of these costs are not necessarily prohibitive for fine orchards or where the other costs are very low, they definitely limit the profitable operation of

mediocre and poor orchards. The cost of pumping water to high elevations is frequently a limiting factor, even when the cost of the water is low.

When water cannot be obtained from established companies, it must be developed by the grower. Capital investments in 1933 for this purpose were said to vary, in California, from $4.60 to $91.18 per acre (Adams and Huberty, 1933). The costs are ordinarily least for orchardists having riparian rights to surface water flowing adjacent to or through their properties, and highest where water must be pumped from deep wells and transported some distance or to high elevations. It is frequently uneconomical for the owner of a small property to develop his own water supply.

## CAPITAL INVESTMENT

The profitableness of a citrus enterprise is obviously influenced by the total expenditures necessary for land, water rights, equipment, improvements, and planting, and for bringing the orchard to a self-sustaining age. These capital investments vary greatly with local conditions, and should be carefully estimated when locations for planting are being decided upon. Comparisons should be made on the basis of the value of established orchards. It may be more profitable to buy a producing orchard than to develop one.

### COST OF LAND

In districts not generally given over to citrus culture the price of land may depend on its value for other agricultural or even for nonagricultural purposes. In many areas where the chief product is citrus fruits, land prices depend primarily upon its value for the raising of these fruits. Careful distinctions between the factors influencing land prices should be made when considering land for purchase. Suitable lands for citrus production should always be chosen. There are enough of these to produce all the citrus fruits that can be marketed. The planting of lands that will support marginal or at best only fair citrus orchards is unwise and should be strongly discouraged.

### PREPARATION OF LAND FOR PLANTING

The cost necessitated in the preparation of land for the planting of citrus trees is a capital expenditure, and should be added to the original cost of the land in order that comparisons may be made between various properties under consideration. These expenses vary greatly in amount. The nature of the topography is especially important in irrigated regions. If the land is uneven, grading may be necessary to obtain uniformly sloping surfaces suitable for satisfactory irrigation and for the removal of surface water during heavy rains. The value of most soils is greatly decreased by the removal of surface soil in grading, and this should be reduced to a minimum. If the natural slope is steep, contour planting or the construction of terraces will be necessary.

The nature of the soil frequently influences the cost of clearing the land. Thus the removal, from stony land, of rocks that interfere with cultivation and other orchard operations necessitates a labor cost. Such expenses have

sometimes equaled or exceeded the cost of the raw land. Figure 98 shows stony land in the foothills of California being prepared for planting. The operations consisted in clearing away the native vegetation, grading, and the removal of large stones. Part of the stones removed from ten acres are shown in the right background. The total cost of this work was approximately $1,000 an acre. Only the most highly prized land, when purchased at a low figure, can justify such an investment. Data of average costs of land preparation in California and Florida are not available, but perhaps do not exceed $50 an acre.

Fig. 98. An extreme example of expenditure of effort in the clearing and leveling of land preparatory to planting a citrus orchard. This is a very rocky site, as is indicated (*right background*) by the pile of stones removed from a ten-acre field. The cost of clearing and leveling such land is usually prohibitive.

In citrus areas near large bodies of water, or in regions of high rainfall, artificial drainage may be necessary. This would require ditching or the laying of tile drain-pipe lines. Reliable opinion should be sought on the probable success of such reclamation projects, and the cost should be added to the price of the land.

### COST OF IRRIGATION WATER AND IRRIGATION SYSTEMS

If irrigation systems are to be needed, expenditures will be necessary for the purchase of water rights or stock in water companies or for the development of water. These costs, as well as those for the installation of water distribution systems within the orchard, should be treated as capital investments.

### OTHER CAPITAL EXPENDITURES

*Equipment.*—Orchard heating is not universally required, or may not be necessary to the same degree in all citrus areas, but all investments in equip-

ment necessary for this operation should be added to the cost of the orchard. (The equipment required for this operation is discussed more fully in chapter xvii.) Annual charges for depreciation and replacement on equipment should be put down as items of expense.

The capital value of other equipment should also be estimated in the same manner. The cost of cultivating equipment, and so on, may vary in different citrus regions, or even locally, with the methods of carrying on cultural operations.

*Taxes as they affect capitalization.*—Taxes on citrus lands vary greatly in different regions. Locally there will also be some variation, owing to the imposition of one political unit upon another. Thus one agricultural area will be subject to county taxes, taxation by cities, and further taxation to support school or improvement districts, while a near-by locality will have only part of these taxes to pay. For the purposes under discussion, the average total annual tax bill expected should be considered in the selection of the orchard location. In order to compare locations, the annual taxes may be capitalized at a fair interest rate and added to the cost of the land.

*Cost of trees and their development.*—The cost of nursery trees varies from one period to another, depending on the supply and demand, more than from one citrus region to another. The cost of nursery trees may seem prohibitive, or suitable trees may not be purchasable at any price. The operation of the orchard until its production makes it self-sustaining will vary with local factors and with income from marketed fruit. These items should be estimated carefully.

## ADDITIONAL PROBLEMS OF LOCATION

Certain other matters must receive consideration before satisfactory sites can be intelligently selected; not infrequently, they will be of decisive importance. The presence of pests and diseases, and the economic loss which they cause, must be taken into account. The facilities for a successful farming enterprise must be present, including those needed for picking, packing, and marketing the crop, as well as the labor supply for general orchard care. And various personal requirements must be met.

### PESTS AND DISEASES

Citrus orchards in some localities are subject to diseases and insect pests that are not present in all. For example, lands infested with oak-root fungus, *Armillaria mellea,* are of less value. This disease is sometimes found in California and Australia where native oak and sometimes other trees have grown. Examination of the roots of native trees to determine the presence of the disease should be made before they are destroyed. Certain diseases of the crown roots and base of citrus trees, such as gummosis and root rot, are more prevalent in some citrus-growing regions than in others, and should be well understood (Fawcett, 1936). Heavy soils are especially likely to contribute to their incidence. Control of diseases of the roots cannot always be avoided in areas where they are especially virulent. The various rootstocks differ in their susceptibility to these as well as to other diseases.

The distribution of insect pests of citrus trees also varies with different citrus-producing regions. The citrus white fly (*Dialeurodes citri*), the Mexican fruit fly (*Anastrepha ludens*), the Mediterranean fruit fly (*Ceratitis capitata*), and other pests (Quayle, 1938) are examples. Quarantines have been erected in some markets against the movement of fruit from infested regions, and the prospective citrus grower should satisfy himself that the yield, fruit quality, or marketing of his fruit will not be adversely affected by them.

Certain scale insects, citrus mites, and thrips have climatic adaptations that limit their range. Also, strains of these insects develop resistance to certain insecticides, and hence they are much more difficult to control in some districts than in others. The importance of these insects and the efficacy of control measures in specific areas should be studied carefully. They may be the deciding factors in the choice of an orchard site. In some sites which border on uncultivated lands the control of rodents may be ineffective, and this fact alone may make the location unsuitable. (See chap. xiv.)

### LABOR SUPPLY, PACKING, MARKETING, AND TRANSPORTATION FACILITIES

The size of the orchard and the stage of development of the citrus industry in a particular locality have a bearing upon the labor requirements that should be anticipated in selecting an orchard or an orchard site. Even in small orchards, where most of the operations can be performed by the owner, some phases of citriculture can ordinarily be done most effectively by contract or by the coöperative efforts of groups of growers. Harvesting of the crop is an example. Pest-control operations are often thus carried on. Frequently, the operations that require large investments for equipment, or that are performed by large, experienced crews, can be carried out more economically by collective action.

In California, there are a few coöperatives that supervise all orchard operations. In Florida, this service is frequently performed under the direction of the packing-house personnel.

The facilities that may be available for packing the crops should be carefully considered. A fairly large volume of fruit is necessary for the economical operation of a packing plant, and since this operation requires special knowledge and skill, few producers are in a position to prepare their own fruit for market. Usually, this work must be done either by commercial packers under contract or by a coöperatively owned packing house. Facilities for carrying it out must be available at a fair cost. Availability of plants for processing fruits is also an advantage. The marked expansion of the processing industry in recent years makes this factor of great importance in most regions.

Marketing facilities for fresh fruits must also be available. Since citrus fruits are largely sold in regions far from the area where they are produced, it is impossible for most growers to sell their fruit on the market personally. Consequently, most selling is done by commercial buyers, brokers, or coöperative marketing agencies.

The movement of fruit to the packing houses is facilitated by good roads. Shipping of fruit to market is done by truck, railway, or ship. Packing and processing plants are ordinarily situated where good transportation facilities are available. Storage houses or refrigeration facilities are sometimes of value in maintaining the quality of fruit in storage before shipment, and thereby permit more uniform shipment to markets over longer periods of time.

### PERSONAL CONSIDERATIONS

The above-mentioned factors are important in the selection of a citrus orchard site or of an established orchard so far as they affect the efficiency of fruit production and the economics of orchard operation. The number of variable factors discussed should not discourage growers, since many are satisfactorily fulfilled in most areas where the growing of citrus trees is feasible, and not all of them apply with equal weight to each situation. However, one or more of the requirements may be so unsatisfactorily fulfilled as to make the growing of these fruits hazardous or impossible.

Several additional items, some of which are more or less personal, may influence the desirability of a site. Proximity to satisfactory educational facilities, churches, stores, and neighbors may be a prime consideration. So may ease and cost of transportation. The value of the property as a homesite is frequently of importance to the orchardist; and the availability of electric light and power, gas, and domestic water and telephone service should therefore be considered. Each grower should evaluate his own requirements and desires with respect to these items.

## BUYING A BEARING ORCHARD

It will often be more profitable to buy an orchard than to develop one. The costs of development are included in the purchase price and hence are known definitely. Production begins at once—a factor of importance at a time when the economic status of the industry is undergoing changes. The operator's personal qualifications and interests may make it preferable for him to start with a mature orchard. The factors which are important in the selection of the orchard site should also receive attention; and certain additional matters should have special consideration.

The age of the trees, their variety (or clone), and the planting plan should be taken into account. The general vigor and health of the individual trees and of trees in the vicinity should be noted. The nature of the rootstock should be determined, especially in regions where sweet orange and other citrus trees on sour orange roots are susceptible to tristeza or to orange-tree quick decline. (See chaps. iii and xi.) The presence of pests and rodents should be noted, and the degree to which control measures are successful should be determined. Diseased and nontypical trees should be enumerated, and the reasons for the abnormalities should be noted and evaluated. The presence of psorosis (scaly bark) in young and old trees should be determined; this is particularly important for orange and grapefruit trees, and desirable for lemon. The costs of the replacement of unsatisfactory trees should be considered. An orchard map

or record showing the type and conditions of individual trees is a practical assistance in making these studies.

An accurate history of the yield records, of costs of insect-pest control, and of returns should be obtained wherever possible. Such data are frequently available in the records of packing organizations. Orchards which have *never* produced satisfactory crops should be regarded with suspicion; they may be incapable of profitable production. Wherever it is possible to do so, the causes of poor production or of unsatisfactory fruit quality should be determined; they may indicate the frost hazard or other undesirable conditions. Inspection of the orchard should be made for any nutritional deficiencies that may exist. Information on the fertilizer practices followed should be obtained, including a history of applications of organic materials as well as of inorganic fertilizers. On the sandy soils of Florida, determinations of hydrogen ion concentration are used as an aid to the study of the fertility level (Camp, 1939). Data on the costs of operations, as well as of gross returns, are essential in determining the value of an orchard. Orchards which have been nonprofitable over a series of years, or for which the prerequisites for successful results cannot be confidently diagnosed and readily fulfilled, should be classed as purchases of doubtful merit.

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## Chapter V

# PLANNING AND PLANTING THE ORCHARD

BY

RALPH G. LaRUE and MARVIN B. ROUNDS

Laying out the orchard, planting, and care of the young trees are vitally important to the ultimate success of a citrus-growing enterprise. Once a site has been selected for the orchard, the grower should begin looking for the best nursery trees obtainable, and should plan for efficient cultivation, irrigation, drainage, and erosion control, and for access to the orchard for all other necessary operations.

Much of the citrus acreage of the United States is on nearly level or slightly sloping lands, which usually require little leveling and grading and may be planted in accordance with some standard system of regular rows each way and still be successfully irrigated and cultivated. Many of the warmest lands, however, are on hillsides, where satisfactory irrigation and cultivation cannot be practiced except by the use of contour planting or terracing. Plans for setting out the trees, irrigation, drainage, grading, and leveling must be decided upon prior to the time of planting, so that the land may be ready to receive the trees at the proper season. (For some of these factors to be considered in selection of the site see the preceding chapter.)

## TYPES OF PLANTING AND PREPARATION OF LAND

### STANDARD PLANTING

*When should standard planting be used?*—The term "standard planting" refers to plantings made on lands the topography of which permits an orchard to be planted in straight rows, with trees in the rows set a uniform distance apart. With such plantings it is not necessary to reduce or increase the grade in order that irrigation, drainage, and cultivation may be properly dealt with. Most citrus orchards of the world are planted in this manner.

In humid countries, where the natural rainfall is sufficient to maintain production, the standard planting arrangement of the trees can be used more generally than in arid countries, where provision must be made for irrigation. Where irrigation is required, the degree of slope of the land upon which a standard planting can be made depends upon the relationship of the grade to the soil type that is to be planted. The grade allowable is dependent upon the soil type, the length of run for the irrigation water, and the size of stream to be used. A greater slope or a larger stream is required on a light sandy soil, where water penetration is more rapid, than on a heavier soil with slower penetration. The main difficulty on the heavier soil is danger of erosion from heavy rainfall and rapid-flowing irrigation water. On very light sandy soils, grades of less than 1.0 per cent (1 foot in 100 feet) are not satisfactory for furrow irrigation if the run exceeds 200 feet. On the other hand, grades in

excess of 3.0 per cent may favor a uniform application of water, but the problem of erosion is then increased. In general, any site with a grade of less than 0.5 per cent or more than 3.0 per cent should not be planned for standard planting unless length of run, size of irrigation head, method of application, and erosion control are determined beforehand with respect to the soil type. Contour planting may be necessary for best results when the grade exceeds 3.0 per cent. When the grade is less than 0.5 per cent, some system of flooding with checks should be used. All factors of soil management are directly related to the allowable grade.

On slightly rolling lands where the grades permit standard planting, the direction of the rows must be changed with the changing direction of the slopes. Unless the fall is uniformly in one direction, each site presents a different problem of arrangement requiring careful study if the most satisfactory planting and irrigation are to be obtained. Combinations of contour, terrace, and standard plantings are frequently necessary, to conform to changing slopes and soil types. Employment of a civil engineer in preparing the land for planting will commonly be found a profitable investment.

*Preparation of the land for irrigation.*—It is always desirable, unless the lay of the land is obviously of proper grade throughout for the irrigation desired, to check it with a surveyor's level. Slight depressions or ridges, or areas of almost level ground, may make the orchard hard to irrigate properly; hence these slight irregularities should be corrected. Small irregular areas do not always reveal themselves on even the most accurate contour maps, but must be determined by the taking of intermediate levels. If the irrigation system is installed before the trees are planted, a trial irrigation will show up the irregularities. Very little change in the irrigation and drainage system can be made after the trees are set, and then only at some expense. It is therefore advisable that all possible corrective operations be completed before planting. (See fig. 99.)

Installation of the irrigation and drainage system should be planned before final preparation of the land is made. It is desirable, though not imperative, that the irrigation system be completely installed before planting.

If leveling or grading must be done, it should follow the design of the irrigation system. Preparation for actual planting begins with the land leveling. On deep, recent, alluvial soils a fair amount of grading can usually be done without uncovering sterile soil. Unless the surface soil is deep, none of it should be removed to another location; trees are not likely to grow successfully in that part of it which was subsoil, because of its adverse physical condition and lack of fertility.

The land should first be cleared of any brush and undergrowth that cannot be plowed under. If the soil is rocky, the large rocks should be removed. Weeds and small growth may be cut with a disk harrow, if that is practicable, and then plowed under with an ordinary turning plow. This kind of clearing should be started several months before planting time, so that organic matter turned under will have time to decay. If plowing is done in the fall, winter rains help materially in decomposing it.

Much of the leveling of an ordinary piece of land can be done with a homemade float. A float consists principally of two runners, usually 2 by 12 inch planks (or lighter planks for smaller sizes) from 15 to 30 feet long, set on edge and spaced 6 to 10 feet apart. Crosspieces, serving as cutting bars, one at each pair of ends and two or more equally spaced in the interval, with diagonal braces on top, hold the planks rigidly parallel. The runners and cross members are usually shod with iron strips. Many variations in type of float are possible, the size depending on the power available to pull it and the

Fig. 99. Well-engineered citrus planting: full advantage taken of contour and straight-row planting for proper irrigation and erosion control. (Photo by Maurice Donnelly.)

leveling to be accomplished. Dragging one of them back and forth will often put a rough piece of land into fine shape, leveling off small humps and filling in small depressions. When it is necessary to grade the land by cutting and filling with a scraper, finishing it with a float will be found effective. The soil should be in as good tilth as possible. A year's preparation by cover cropping and manuring, with deep plowing, will contribute materially to the success of the young orchard, especially if the planting is on poor soil.

*Irrigation methods used in standard plantings.*—Any type of irrigation may be used in standard-planted orchards. Furrow irrigation is most common where the grade permits easy flow of water without erosion. On lands so nearly level that the water will not flow through the furrow at such a rate as to give uniform penetration, irrigation by means of basins or checks may be found more satisfactory. Either the basin or the check method requires a larger volume of water than furrow irrigation. Sprinkling systems may be used for any system of planting. (See chap. x, pp. 453, 461.)

## CONTOUR PLANTING

*When contour planting should be used.*—In contour planting, as the name indicates, the tree rows are established along a uniform slight grade. Such planting should be used when the land is on a hillside or rolling and the slopes are such as to render irrigation difficult and erosion a serious danger. If the slope of the land is too steep for irrigating a given type of soil, the planting should approximate the contour lines but should be so graded that the irrigation furrows will accommodate the volume of flow necessary for adequate penetration without erosion.

If the cross slope of an orchard exceeds about 5 per cent, it is generally unwise to cross-cultivate since erosion in the middles will eventually result in irrigation difficulties and loss of fertility.

Generally, contour planting of orchards is common on slopes exceeding 3 per cent, though standard plantings with sprinkler irrigation are sometimes employed. Contour plantings are employed mainly to avoid erosion.

Disadvantages include: difficulties in irrigating because the lengths of tree rows vary; danger that water may break down the cross slope; and troublesome weed control. Contour planting increases the costs of harvesting, cultivating, pest control, and orchard-heating operations.

*Problems of contour-grade plantings.*—Planting on terraces or on contour grades almost always results in irregular planting distances. Many growers prefer to keep straight rows on the cross slope, in order to permit cross-cultivation where possible, facilitate more efficient irrigation, and simplify heating operations.

Where the type of contour planting is used that gives uniform spacing of trees along a contour grade, without regard to alignment across the grade, the rows do not usually form smooth curves, and the cross rows are not straight. The most nearly uniform grade in the furrows is attained by this method. Where cross rows are kept straight there must be uneven spacing along the grade contours, and usually a smaller number of trees per acre results. The first method is preferred where slopes are steep and irregular.

A third method of contour planting, preferred with long, more even slopes, is one of varying grades with straight cross rows. This method provides a smooth curve along the tree row and is an advantage in cultivation. It can be used where the cross slope is not too steep and is relatively uniform. Care must be exercised not to vary the grade too much, as may result from moving the trees too far. Generally the contour grade must be within the range of 1.5 to 3.0 per cent to allow for the necessary variance of grade.

*Irrigation of contour plantings.*—Both furrow irrigation and sprinkler systems are used on contour plantings in California (Huberty and Brown, 1928). Watering by means of individual tree basins is also practiced, the water being distributed by means of a main ditch or furrow parallel with the tree row. The contour check method is sometimes used on contour plantings where large heads of water are available (Brown, 1933). Furrow irrigation is the method commonly used, however.

Irrigation distributing systems should, when possible, extend down the slopes with the least grades. Contour rows starting from such distributing lines will therefore tend to pinch out when they extend into the steeper slopes, and result in point rows. Irrigation water can then be easily run into furrows converging from adjoining contour rows. If the rows run from the steeper slopes onto flatter slopes, filler rows will be necessary. This necessitates stub irrigation lines or split furrows in order that irrigation water may be applied to rows not starting at the pipe line.

Fig. 100. Preformed bench terraces, which have been quite generally used in lands where the slope is steep. (Photo by U. S. Dept. Agriculture Soil Conservation Service.)

Once the plan is decided upon and the orchard is set, the likelihood of its ever being changed is quite remote. A citrus orchard is a long-time enterprise, and many years of difficult problems—which may end in failure—face the grower who does not carefully weigh all factors and choose a satisfactory planting plan.

USE OF TERRACES

The type of bench terrace called "preformed" has been quite generally used in preparing the land for planting fruit trees where the slope is rather steep (fig. 100). In general, primary soils found on steep slopes have a shallow surface horizon and a comparatively infertile subsoil. Because the relatively shallow surface soil should be disturbed as little as possible, it is seldom economically practical to make terraces prior to planting lands that have slopes exceeding 15 per cent.

Since, with contour plantings on steep slopes, cultivation can usually be done only along the grade, contour terraces generally develop over a period

of years. Such terraces are desirable, but not so desirable as preformed terraces that are built before the plantings are made. If the terrace widens out beyond the average row width and another row can be inserted, a filler row is started. When the terrace becomes too narrow for working, usually not exceeding 14 to 16 feet, it is discontinued, forming a point row.

In any contour planting the tendency for the soil is to work down the slope. This will occur even under exclusive contour cultivation (fig. 101), and a frequent result is that the bases of the tree trunks become buried, necessitating periodic handwork in pulling the soil away from the trunk and the bud union. The best solution may be to adopt such cultural practices as will minimize or eliminate cultivation (fig. 102).

Fig. 101. Orange trees on a bench terrace produced gradually by cultivation.

## DRAINAGE

### DISPOSAL OF SURFACE DRAINAGE

Provision must be made for the disposal of surplus drainage water, irrespective of the type of planting. On contour plantings, irrigation furrows along the contour grade are commonly provided for this purpose. At the end of such a grade the accumulated runoff should be carried down the cross slope through drain-pipe lines (fig. 103), or through ditches that have been stabilized with vegetation or check dams. It is generally desirable to have the contour grades extend toward natural drainage channels. Where contour plantings are terraced, or have become terraced, it may be well to provide a drainage furrow or ditch near the toe or upper edge of the bench, near the riser.

Ditches are usually cheaper and are easier to run water into than underground systems. However, they are in the way of cultivation operations unless a suitable area is left for a turning space between the ditch and the last tree. This often results in a weed problem and waste land, as cultivation cannot be very close to an open ditch.

Underground concrete pipe with risers or downspouts so placed at the end of each row as to catch the accumulated waste will dispose of surplus water. They must be out of the way of cultivation and at the same time in a position to receive runoff water.

The chief objection to the use of underground conduits is the cost. There is also the necessity of some handwork around the risers in mounding up the soil to direct water into them, especially where the cross slope is great. Relatively, only a small amount of weed control around them is necessary. Risers sometimes offer a haven to rodents and small animals, which may, under some conditions of accumulating trash, cause stoppage in the system.

Fig. 102. The rise of this bench terrace is protected against erosion by a continuous cover crop. (Photo by U. S. Dept. Agriculture Soil Conservation Service.)

## SUBSURFACE DRAINAGE

Subsurface drainage is usually important in saline soils, or where the irrigation water has a high concentration of salts that may accumulate in the root zone in sufficient quantity to be toxic to trees (Weir, 1926).

Where the soil profile is such that natural drainage will occur, little difficulty is likely to result even with the use of water containing some salts. Under these conditions, with leaching by rainfall and the proper type of irrigation practice, the salt concentration in the root zone may be kept down so that injury will not result. However, where there is a shallow subsurface stratum of heavy or impervious soil that prevents free percolation of water, areas with salt accumulations or waterlogged land will probably result. It then becomes necessary to install subsurface drainage, which usually consists of a clay tile pipe placed at the minimum depth at which the free water surface must be maintained. Intercepting drains may be necessary, where steep slopes occur, to prevent water from following an impervious layer to a lower level and causing a waterlogged condition. In running out the grade for the tile the slope of the impervious layer is then followed, rather than the soil surface level.

In certain large areas of land with slopes suitable for drainage the water table has been lowered, and the salt content reduced, so that citrus can be

satisfactorily grown. This has been accomplished by the installation of extensive underground drainage systems, followed by flooding with water of suitable quality. Indicator plants such as alfalfa, and then beans, were grown

Fig. 103. Downspouts to underground drainage conduits. Notice that opening is on upper side of pipe. These openings are sometimes screened to keep trash out.

in order to show when it would be safe to plant the citrus. Such development requires farsighted planning, with ample finances to see the project through. It also involves risk, if the program should fail (Hart, 1915; Weir, 1926).

### PLANTING ON RIDGES TO FACILITATE DRAINAGE

Planting on ridges or mounds is frequently practiced in the Far East and to some extent in Florida, where land surfaces are so flat that drainage is slow and water tables are near the surface (fig. 104). It is generally followed in

parts of China, Japan, Java, Siam, and Indo-China, where rainfall is heavy. Under lowland conditions in these countries, water may stand on the surface for long periods, owing to poor drainage.

In the Far Eastern countries, pummelos are commonly grown on mounds and ridges in marshes cleared for planting. The ridges and mounds, formed by digging out drainage ditches and mounding up the planting bank, provide drainage for the very flat lowland (Groff, 1930). These banks are further built up, over a period of years, as mud is dug from adjoining ponds for fertilizer (Condit *et al.*, 1937). The pond mud is deposited in chunks along the tree ridges, where it dries out and can be spread, adding organic matter and some soil. With such mounds or ridges, as illustrated in figures 104 and 105, only handwork can be used for any cultivation practiced.

Planting on broad ridges has proved good practice in Florida (Hume, 1926) on some low muck soils of the Everglades and in many flat areas where drainage is poor and moisture is likely to be excessive during certain seasons (Stirling, 1935). In California, similar methods are sometimes used to improve poor drainage conditions. The low ridges are formed by backfurrowing with a plow to the tree row one or more times before planting, thus making a rather deep furrow in the middle. Trees are planted along these ridges. Irrigation and cultivation are then carried on as usual; but if the orchard is cross-cultivated, the trees may be left growing on separate mounds. This may be in some measure avoided if, in cultivation, the dirt is thrown toward the trees. Where the rows are double-planted in accordance with a permanent plan, as frequently with lemons, the ridge is not disturbed, since cross-cultivation cannot be practiced.

### SUBSOILING AND BLASTING TO IMPROVE DRAINAGE

Any subsoiling or blasting to improve irrigation and drainage should be completed before the trees are planted. Subsoiling, to break up dense subsurface layers of soil and thin layers of hardpan, is usually limited to running a subsoil plow along the tree rows both ways so that the furrows cross where the trees are to be planted. Once the trees have attained a fair size, subsoiling can only be done at the expense of severe root pruning, which seriously affects the condition of the trees. Their recovery will be slow. (Anon., 1929.)

California has pioneered in the use of blasting to loosen hard layers of subsoil, which frequently occur at shallow depths and overlie a permeable substratum. Many citrus orchards in the most productive districts of the State are on soils underlain at shallow depths with hard subsurface layers that have been broken up. Where this hardpan lies at depths of approximately three feet or more, little or no effort is made to disturb it if drainage is not a problem. Most commonly, blasting is limited to breaking up hardpan in the tree holes and close around the place where the tree is to stand.

Blasting holes for trees is not to be recommended unless the entire thickness of the hardpan can be broken, since a loosening of only a part of an impervious layer will frequently result in a pothole that retains water and thus kills the tree roots. Blasting should be done only by qualified powder handlers and

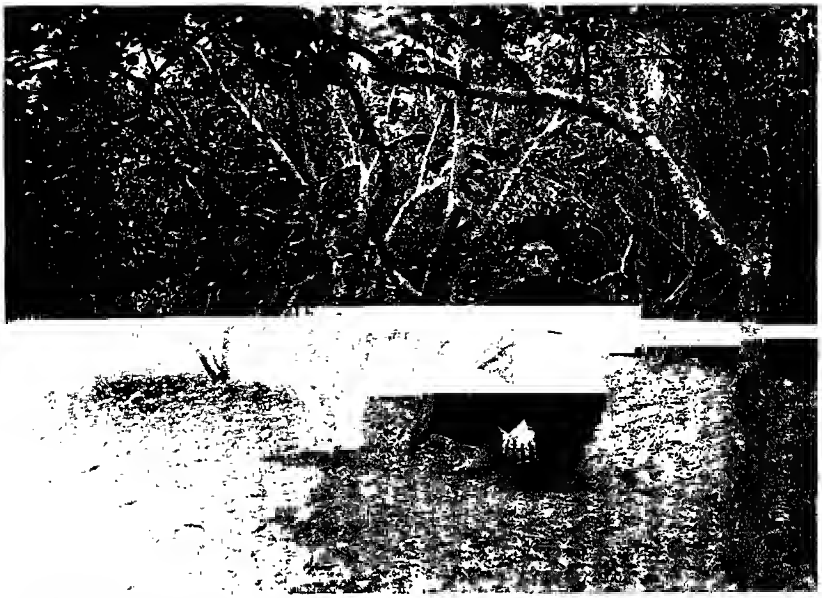

Fig. 104. Mature grove near Tailoku, Formosa, illustrating the height to which the trees have been ridged to provide drainage away from the trunk. (Photo by Dr. I. J. Condit.)

Fig. 105. Typical lowland orchard near Swatow, China, planted on ridges made by excavating the drainage ditch in the intersection. (Photo by Dr. I. J. Condit.)

when soil conditions are favorable for the maximum results. In heavy soils, if blasting is attempted when moisture conditions are not right, potholes will be formed. Some types of soils may break up satisfactorily when dry, but will run together again when wet. These soils cannot be improved by blasting since they are usually of heavy clay or clay loam types and are seldom underlain by pervious layers at reasonable depths. Blasting is adapted only to types of soil that will shatter when dry and not run together when wet. Blasting should be completed well before planting, so that the soil will have time to settle. If trees are planted in the holes too soon after blasting, they may settle so far that resetting will be necessary.

## INTERPLANTING AND INTERCROPPING

### INTERPLANTING WITH CITRUS

In most orchards with standard planting, the trees are set at the corners of squares or rectangles of such size as to accommodate the trees when fully grown. The full distance allowed from tree to tree will not normally be required by the trees for ten to fifteen years, and in the meantime interplanting can often be done to advantage. In fact, with lemons, many growers have adopted a policy of double planting, forming hedgerows, as a permanent planting plan. Double planting to form rather open hedgerows may be especially economical on terraces where cross-cultivation cannot be practiced (Klein, 1936).

The principal objections to such interplanting are the initial cost of extra nursery trees, greater difficulty of cultivation, increased fertilization and irrigation demands during the period of double planting, greater difficulty and cost of pest control, and the cost of removing the temporary trees when they have served their purpose.

The importance of removing temporary or interplanted trees at the time they should come out cannot be overemphasized. Many growers add to their per-acre production the first several years after the trees come into bearing, only to lose production by putting off removing the temporary trees when they begin to crowd and compete with the permanent trees.

In interplanting there has been some tendency to use two or more varieties. This may be desirable, since it permits the retention of the most satisfactory variety for the permanent planting. Ordinarily, however, nothing is gained by mixing varieties, and the difficulties in handling the orchard may be greatly increased. If orchard heating is necessary and the picking seasons do not coincide, it may be found necessary to heat the entire grove to save half the fruit. Heating requirements differ for the fruit and the trees, owing to difference in ripeness of fruit, cycles of growth, or physical resistance to cold. Irrigation practices often vary for different varieties. Harvesting seasons that do not coincide require extra trips through the orchard to remove the fruit, with attendant problems of soil packing due to trucking operations.

Orchards are sometimes interplanted with alternate trees on different rootstocks. The trees on the rootstock that has given the best results by the end of the double-planted period can then be retained.

### INTERPLANTING WITH OTHER TREE CROPS

The possibility of interplanting permanent orchards of citrus with some other horticultural crop with which there is a relatively good plant association merits consideration in certain specialized districts. In Mediterranean countries it is common practice to intermingle grapes, walnuts, pomegranates, and other fruits, under or over which citrus fruits are grown. Although it is probably true that none of these plantings produce a normal per-acre production for any one fruit, certain combinations of crops may satisfactorily and profitably mature together.

Citrus in its native habitat is usually found in very humid tropical jungles, growing under the larger native trees, along river banks, under very moist conditions. In Florida, many of the finest groves are planted under the native palmettos, oaks, hickories, and pines, with no more than a thinning out of the trees that occur in the place to be occupied by citrus (Hume, 1926). In the oases of northern Africa, citrus is grown in a haphazard manner under date palms. In the Coachella Valley of California, an area with a long growing season, relatively high summer temperatures, and low humidity, date palms and citrus trees interplanted are being grown successfully. In the more humid tropical countries such plants as pineapples have been grown as intercrops.

In the growing of any intercrop the relation of the cultural practices of one crop to those of the other must be carefully considered.

### INTERPLANTING WITH QUICK-MATURING CROPS

Intercropping the orchard while young with quick-maturing cash crops is usually desirable to provide an income while the trees are developing. Beans, peas, corn, and other vegetable crops are frequently grown (Vaile, 1918) (fig. 106).

Beans make a very good intercrop. When the beans are threshed, the straw can be returned to the soil. If corn (maize) is grown, it provides suitable material with which to wrap young trees for winter protection. However, most of the cereals are gross feeders, and serious competition with the young trees may result from their use. General truck crops can be grown successfully as annual cash crops and thus give some returns where such crops are in demand. It has been observed when alfalfa is grown as an intercrop that competition results in lower yields of citrus fruit. In growing any intercrop the good of the permanent citrus must be considered as primary, and the secondary crop should be grown only with a minimum disadvantage to the citrus. It should also be remembered that the production of such annual crops in citrus orchards is not likely to be desirable or profitable except during the first three to five years of the orchard's growth. Hence they should not be planted too close to the trees.

Interplanting or intercropping offers an opportunity for the original developer of the land to use a greater part of the area planted for earlier higher production per acre. The type of interplanting or intercropping may well be determined by the number of years he will be interested in the project.

## LAYING OUT THE ORCHARD

### PLANTING DISTANCE

*Factors influencing planting distance.*—The first factor to be determined in planning the arrangement of the orchard is the planting distance, which will differ with the space requirements of the variety to be used. If the orchard is to be double-planted, the permanent trees should be set nearer the maximum distance for a permanent orchard of the variety set out.

Fig. 106. Lima beans as an intercrop in a young lemon orchard, Orange County, California. This orchard is set with rows a maximum distance apart to provide for many years of intercropping with these beans, which are profitable in this district. Notice the furrow irrigation practiced while the beans are bunched ready for threshing.

On very rich productive types of soil, where the tree spread will ultimately be comparatively great, wide planting distances should be considered; it is undesirable for trees to be crowded so that the tips of their branches cannot extend close to the ground. Trees forty years old or more, if lacking proper space, will not permit movement of cultural equipment through the orchard. Planting by the quincunx method, whereby semipermanent trees are set that are to be removed before crowding, will result in a permanent orchard set on the square. The problem here is to make the necessary decision to remove the semipermanent trees before the permanent ones are crowded and before the fruit-bearing surface on the permanent trees is reduced.

*Planting distances required by different varieties.*—Planting distances in most citrus districts vary greatly. If the orchard is to be double-planted or set quincunx, the planting distance will depend upon the length of time the temporary trees are to remain.

The planting distance depends a great deal upon the variety, the species of rootstock used (see chaps. ii and iii), fertility of the soil, and the length of the growing season in the district. Standard stocks, from which the greatest tree size will result, will necessarily require a wider planting distance than stocks with dwarfing or semidwarfing effect. This is especially true where any double-planting plan is considered. Certain stocks might be selected for their rapid development, especially for interplanted or temporary trees, which would not be so satisfactory as a slower-growing stock for the permanent trees. The spacing distance for citrus trees varies greatly with these factors affecting tree growth.

In California, the navel orange has grown and borne fruit quite satisfactorily, under ideal soil and weather conditions, when planted at spacing distances of 22 by 22 ft. In districts where the prevailing weather is cool, the growing season shorter, or the soils shallow, more trees per acre may be planted, with spacing distances 20 by 20 or 18 by 18 ft.

Valencia trees grow to a larger size under comparable conditions, and although spacings of 20 by 20 ft. are common, usually this is too close. Where spacings of even 22 by 22 ft. are allowed, the branches grow and interlock, and, as the trees advance in age, the consequent shading kills the lower branches.

Under ideal conditions for growth, Valencias should be planted at a distance between trees of from 24 to 28 ft. Grapefruit should be planted at a little greater distance than oranges, varying from 22 by 22 to 30 by 30 ft. In Florida in sandy soils it has been found that a 30 by 30 planting for oranges and a 35 by 35 planting for grapefruit is desirable.

Eureka lemons are usually spaced 22 by 22 ft., but in a deep, well-drained soil, where the weather conditions are satisfactory for growth, the distances should be greater; 24 by 24 ft. would not be too great for plantings in some districts. Lisbon lemons are more vigorous and usually grow to a larger size than the Eureka; hence a planting of 22 by 22 ft. would be too close, and spacing distances of 24 by 30 or 30 by 30 ft. would not be too great for some plantings.

Bearss or Tahiti limes should do well if planted 22 by 22 ft. as a maximum.

Satsuma oranges should grow satisfactorily when planted 18 by 18 ft., and tangerines and other mandarin oranges 22 by 22. Varieties of these become larger in size when grown in the hotter valleys with a longer growing season—a fact that should be taken into account in the planting program.

*Space for roadways and turning.*—Roadways and turning space must be provided in the orchard. The extent of the turning space at the ends of the rows is determined by the type of tillage tools and trucking equipment to be used. Many growers are loath to leave sufficient space. The customary practice is to leave slightly more than half a tree space around the orchard, and some growers increase the planting distance between every other pair of rows so as to provide space for trucking. This is particularly important if orchard heating is to be practiced, since refueling operations make accessibility necessary. (See chap. vi, p. 313.)

### PLANTING BY THE SQUARE OR RECTANGULAR SYSTEM

*Determining the exact planting distance.*—Once the property lines have been determined and the corners accurately located, it is necessary to decide upon the planting distance that will be most economical for the trees and in the use of the site. It is frequently best to determine the planting distances first, and then to make the necessary allowances for turning space around the outside of the orchard; for extra roadways through the orchard; and for such drains and pipe lines as may be necessary. When the sum of these necessary allowances is subtracted from the available space, there will be left the length of tree row in each direction. Dimensions of the net plantable area are then available, which, divided by the planting distances, will give the number of trees per row each way.

If the planting distance decided upon leaves too much turning space at the ends, the distance can be increased or decreased to provide for just the right turning space. It is advisable to keep the planting uniform and avoid odd trees. When the exact planting distance for the trees has been determined, and one boundary has been accurately located to be used as a base line, the orchard is ready to be staked.

*Staking the orchard.*—Measure from a property boundary line the distance at which the first row of trees is to stand, and at this distance set a row of stakes parallel to the boundary to indicate the position of the base row. Locate the first or end tree in the base row by measuring the desired distance from the adjoining, intersecting boundary line, to establish the corner tree position. This tree then becomes the key tree of the planting.

Locate a stake 60 feet from this key tree along the base row, then estimate a right angle from the base row at the key tree and along the new leg of the angle set a stake 80 feet from the key tree. If the distance from this latter stake to the stake set 60 feet down the base row is 100 feet, the estimated right angle is correct and one corner of the orchard is established. From this corner or key tree and the stakes, two rows at right angles may be laid out by use of a planting wire and sighting.

A planting wire is easily made and, if much acreage is to be set, will more than pay for the time spent in rigging it. A piece of 12-gauge galvanized soft steel wire is heavy enough. Lengths up to several hundred feet can be used. They should be cut to conform to the units into which the field is divided for irrigation. A ring large enough for a handhold is firmly attached to one end. Then, at intervals representing the exact planting distance, beads of solder are applied. Sometimes a loop of wire or other device is soldered on, to give greater visibility. When the number of guides desired are soldered on, a handhold ring is attached to the other end. When the first tree position of the base row has been located, the wire is stretched taut between this stake and a guide stake at the other side of the block. Tree stakes are then set by the guides on the wire. When the field is set, the stakes are adjusted by sighting from the ends of the rows before the planting guide stakes are placed.

All stakes must be driven in firmly and set straight up and down so that

any irregularity is instantly apparent. For uniformity in using the planting board (see below), all stakes should be set facing in the same direction.

If flat laths are used, they should be set facing at right angles to the line of furrowing and hauling. The planting board can then be used to set the planting guide stakes in the tree row parallel with the movement of equipment, where they are not likely to be disturbed before the trees are planted.

*Use of the planting board.*—In planting, to gauge properly the exact location of each tree and its height with reference to the soil-surface level it is desirable to use a planting board. When the holes are dug, the tree stake must be removed, and this makes it necessary to have guide or planting stakes for accurate location of the tree.

A planting board is made by taking a piece of 1 by 4 in. board 4 ft. long—sometimes 6 to 8 ft.—and cutting a V notch so that the apex of the V is in the exact center, with notches in the ends in which to fit the planting stakes. The board is used for setting the planting guide stakes, two to each tree location. The stakes are set by placing the central notch of the planting board against the tree stake and driving a stake into each of the end notches. The tree stake can then be removed and the hole dug. The tree is planted by replacing the end notches of the board against the planting stakes and adjusting the trunk of the tree in the V notch.

Planting boards should always be used facing in the same direction, so that irregularities in cutting the notches or in setting the stakes will not cause errors when the tree is planted. Stakes used are generally laths and should be long enough to be seen easily in sighting, but the planting stakes need only be long enough to be firm when driven into the ground.

*Factors favoring the square or rectangular system.*—In any system of planting there is no loss of soil unless the trees are too far apart. Trees set on the square do not confine their root systems to the square or rectangle about them, but permeate the entire area between trees at ordinary planting distances. It therefore appears probable that with normal planting distances all the moisture and plant food will be accessible to the roots. It is for this reason, together with the convenience of a square or rectangular planting in cultivation operations, that most orchards are planted by this system. As many trees are planted to the acre as possible, taking into consideration the future convenience of the orchard for the operations of cultivation, picking, heating, and pest control.

## PLANTING BY THE QUINCUNX SYSTEM

Much confusion has existed in the use of this term. Webster's New International Dictionary (second edition) defines quincunx as "an arrangement, especially of trees, with one at each corner and one at the center of a square." Quincunx has frequently been made to cover almost every kind of planting arrangement not on the square. Probably the easiest method to use in laying out an orchard on the quincunx plan is first to stake it out on the square, adjust the stakes, and then sight through on the diagonal from two directions, locating the central tree at the intersection (see fig. 107).

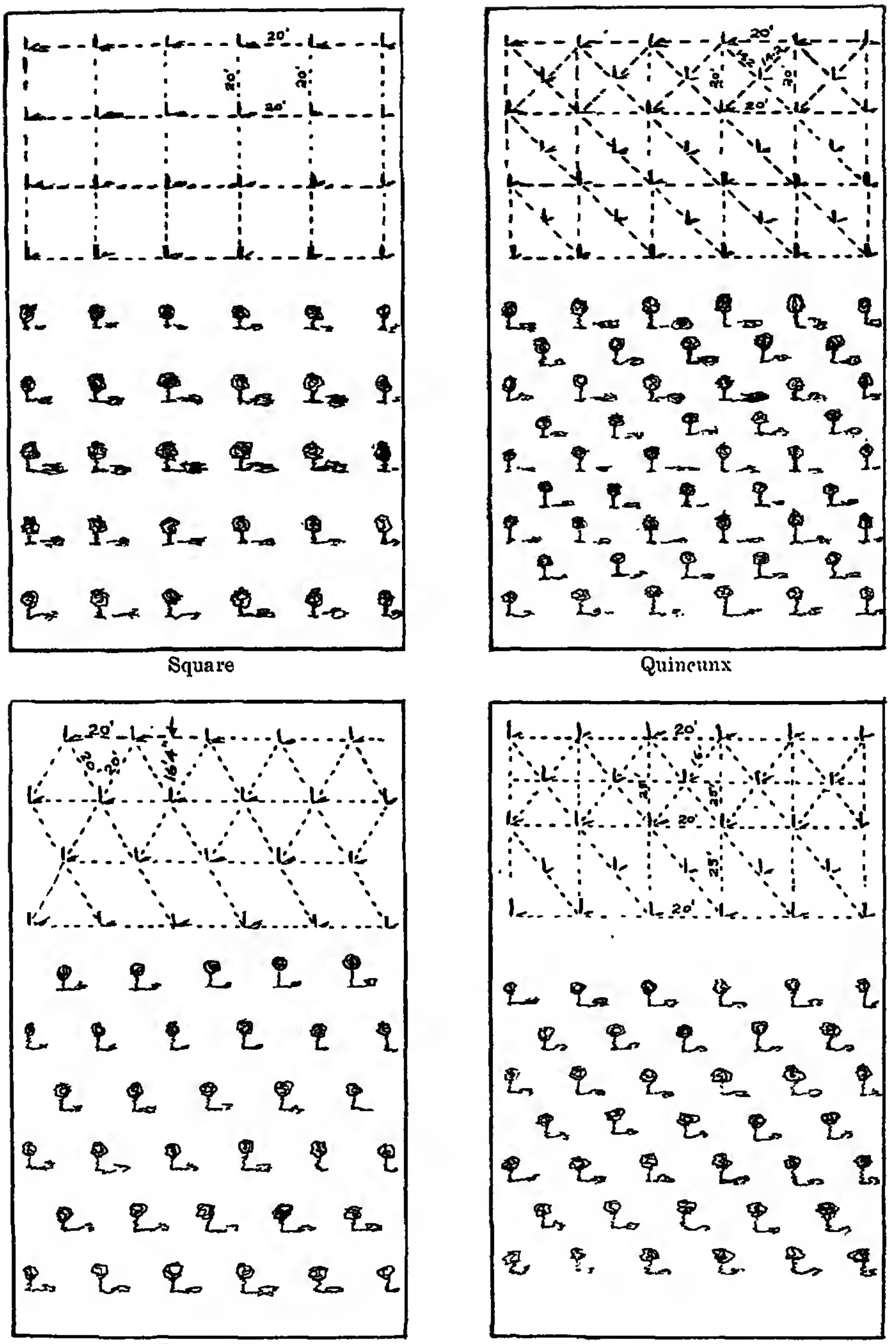


Fig. 107. Planting plans. (Adapted from Wickson, *California Fruits*.)

Setting an additional tree in the intersection of a square by the quincunx method provides for about 78 per cent more trees per acre than the original square planting. As a permanent plan the quincunx is not satisfactory, since crowding results and adversely affects the growth and yield of maturing trees, but it is a satisfactory method for planting additional temporary trees that are to be removed at the proper time. In fact, it offers the best method by which extra trees can be planted and later pulled out, leaving the planting permanently on the square.

### PLANTING BY THE HEXAGONAL OR SEPTUPLE SYSTEM

By this method adjacent trees are all equally distant from each other and the ground is divided as equally as possible. It is hexagonal in that the figure consists of six trees forming a hexagon, enclosing a seventh in the center (see fig. 107).

This method is not common in citrus plantings. It allows for 15 per cent more trees per acre than planting on the square. Other advantages are that the grove can be worked in three directions and variations in running irrigation water are usually made practicable.

### PLANTING BY THE TRIANGULAR SYSTEM

This usually means a triangular planting other than on the equilateral triangle plan. The orchard is set out on a rectangular system, not on the square, with a tree placed at the intersection of diagonals sighted from the corners (see fig. 107). Since the rectangle is longer one way than the other, the tree at the intersection is equally spaced from the four corner trees. This method is similar to the quincunx and is equally as satisfactory for a double-planting scheme if the ratio of length to width of the permanent tree rectangle is not too great.

## PLANTING THE ORCHARD

### DIGGING TREE HOLES

Once the planting stakes have been set by use of the planting board, the tree stakes can be removed and the holes dug to receive the trees. Many young plantings prove unsatisfactory if the tree holes are not dug properly and good soil placed around the roots. To be large enough for ordinary balled or bare-root trees, holes for planting should be approximately 20 inches in diameter and 18 to 20 inches deep. In rocky soil the bottom of the hole should be probed to locate any large stones, which should be removed.

### CARE OF NURSERY TREES

Nursery trees must be handled carefully when first received. The shock of digging is severe, and they should not be subjected to additional exposure, especially to hot sun or wind. If trees are received before the holes are dug, they must be placed in shade and the balls or roots kept moist (chap. i, pp. 36, 38). All nursery trees should be carefully examined before planting to see that the tops have been sufficiently cut back. It may sometimes be desirable to defoliate the trees.

If the trees are delivered in the field, they should not be delivered faster than the planting crew can set them. Trees left in the field should be protected from the sun's rays. Trees delivered to the orchard ahead of the planting crew should be set in the holes in which they are to be planted and leaned toward the south to protect the trunks from the direct rays of the sun.

### THE PLANTING CREW

A planting crew usually consists of two men, with a third to irrigate. One man places the planting board and fills in the soil around the ball. The other cuts the top cord of the ball wrapping and folds it back away from the trunk of the tree, and adjusts the tree in the hole to the planting board, placing the trunk in the V notch so that it is exactly where the original tree stake was set. The bud union is generally placed toward the prevailing wind. It is sometimes desirable to set the bud union toward the south, especially if the tree is to be whitewashed and not wrapped. If it is set so that the sun's rays strike it directly, sunburn frequently results on the curved trunk just above the stub of the rootstock—especially when large rootstocks are budded, since there is then a greater curve just above the bud union.

Trees should always be set somewhat higher in the field than in the nursery, to allow for settling, especially when the trunk of the tree may be exposed to excessive moisture. This may be easily accomplished by nailing a block on each end of the planting board, thus raising the board the desired distance above the ground level. The trees can then be planted uniformly at the desired height by raising the balls up against the board. The use of such blocks in raising the tree provides for settling and for drainage away from the tree trunk.

Dry soil should never be placed around a tree in planting. Clods and rocks should be avoided, and moist topsoil should always be used in backfilling. It is common practice to use topsoil from the area around the hole for backfilling and to use the excavated soil in mounding up a ridge around the tree to form the irrigation basin.

In refilling the hole, dirt should be well tamped in around the ball. This can be done by partial filling and tamping by use of a shovel handle. If the tamping is not carefully done, it is better to rely upon water for settling. Bridges of tamped dirt may occur over pockets that are difficult to fill and that may be missed entirely, resulting in a poor soil condition around the roots.

### IRRIGATING NEWLY SET TREES

*First irrigation.*—Irrigation should follow immediately after setting the tree. Even with the best of tamping, it is necessary to settle the dirt with water so that the soil will be tight against the ball, thereby disposing of all air pockets. It is important that the water surround the young tree entirely, filling the tree hole so that all parts of the soil will be thoroughly settled (fig. 108).

As a result of this irrigation around the ball, trees will usually shift and many of them will be out of line. They should be gently straightened not later than the next day. If a tree has settled too far to be pushed back easily by

pressure on the soil, a shovel should be inserted beside the ball and moved carefully so as to straighten it. Too much moving should not be attempted. Trees leaning slightly toward the prevailing wind may be desirable and will not make a noticeable difference after the first year, even though they may be several inches out of line.

*Second irrigation.*—When the trees have been straightened, the ball should be completely covered with soil and a basin made around the tree somewhat larger than the tree hole. It is desirable to fill the basin with 3 or 4 inches of

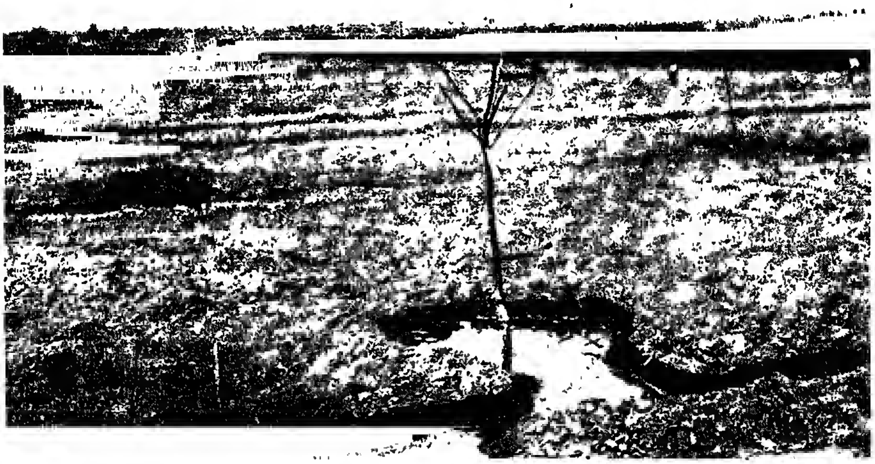

Fig. 108. Common method of irrigating newly set trees in California where a small head of water is used in a furrow. (Photo by Dr. H. J. Webber.)

organic mulch such as bean straw, cereal straw, alfalfa hay or straw, or even very strawy manure if this last is kept away from the trunk of the tree.

The planting is then ready for a second irrigation a few days later. The application of irrigation water should always depend upon the moisture requirement. Since the root zone of a young tree is small, an examination close to the tree should be made. The root zone of the newly planted tree is entirely within the ball of 30 or 40 pounds of soil, which does not contain much moisture. If irrigation is not frequent, the moisture in the ball, and therefore the root zone of the tree, may become exhausted even though the surrounding soil may have an adequate supply.

The trees should be watched when they are beginning to grow, to discover if any do not start promptly. Often, when trees are balled from a nursery on soil heavier than that in which the trees are set, water will not penetrate the ball, but will drain down beside it. If upon careful inspection a dry ball is found, it must be cracked with a probe so that water will penetrate it.

The reverse of this condition may result if trees balled in light soil are

planted in heavy soil. Water may accumulate in the hole and ball, causing the roots to rot, if irrigation is not carefully managed. The ideal condition obtains when the texture of the soil in which the trees are to be planted is about the same as that of the nursery from which they were removed.

### SETTING BARE-ROOT NURSERY TREES

In humid regions nursery trees are planted "bare-root." This method is not generally used in arid countries, because more care is required in handling bare-root trees than balled trees. Bare-root trees are sometimes given special treatment before they are dug by the nurseryman, to force them into dormancy. In more humid climates this may not be so necessary as it is in California. In planting bare-root, the trees must be dug carefully and packed promptly, so that the roots are never exposed to direct sun or drying winds or otherwise allowed to become dry. In a climate of low humidity, defoliation and early planting are desirable.

Bare-root trees are usually delivered packed in damp moss in large packing boxes lined with oiled paper. The packing moss must not be permitted to dry out. The tops and roots of bare-root trees should be pruned back when the trees are taken from the nursery (see chap. i. pp. 34–35). In planting, they must be handled carefully. Everything must be ready. The trees should be irrigated immediately after planting. Only one tree at a time should be removed from the moss, and if it is not planted right away, the roots should be wrapped in a wet burlap sack to reduce to a minimum the time they are exposed.

When the tree is placed in the hole, *only moist soil must be used in back-filling*. The moist soil should be poured down the sides of the hole so as to make an inverted cone, thus making it possible for the planter to spread and adjust the roots. While they are being adjusted, little tamping or packing of the soil can be done except with the fingers; hence it is necessary to rely upon water to settle the soil in and around the roots. This is done by immediately filling the hole with water enough to soak the soil thoroughly as soon as it is replaced. During rainy periods in humid climates trees may sometimes be planted without watering, but usually a thorough watering is given as soon as the trees are planted. Because of the increased amount of loose soil used in filling the hole in bare-root planting, it is better to set bare-root trees somewhat higher than balled trees, to allow for greater settling. The hole should be entirely filled with soil before irrigation water is allowed to flow into it.

Immediately after watering, the holes should be carefully refilled with moist soil to cover all exposed roots. The trees may be straightened somewhat at this time, but it is dangerous to attempt to lift or pull the tree. as roots that were carefully spread when planted may be stripped off or pulled loose.

After the holes are refilled and the exposed roots are covered. basins similar to those for balled trees should be made, and after a few days another irrigation should be given, and from then on as often as necessary. The first few irrigations, both for balled and especially for bare-root trees, should extend to the trunk of the tree. This type of irrigation is not good practice in older orchards, but it is necessary for best results with newly planted trees. When

the root system is restricted, all the soil containing roots should have available moisture.

*Advantages of bare-root trees.*—Bare-root trees have some advantages over balled trees. They are much more economical to handle and ship if they are to be moved any great distance. As an example, California nurserymen have successfully shipped thousands of citrus trees to Brazil and South Africa. The trees had to cross the tropics, and thus were subjected to extremes in temperature; they were in transit some three to five weeks, during which time it would have been almost impossible to maintain proper moisture with balled trees, and uneconomical to ship so great a weight of soil along with the trees.

In order to ball a tree it is necessary to cut off all lateral roots three or four inches from the center taproot and reduce this root to the depth of the ball. Bare-root trees are usually dug from larger holes, leaving much more of the root system. Bare-root trees leave the root system available for careful examination, so that trees with poor roots can be discarded, and cross roots and ragged ends can be trimmed or eliminated. Planting trees bare-root also makes it possible to treat the root system with a fungicide for prevention of brown-rot gummosis.

If trees are properly handled, from nursery preparation and digging to planting, and properly cared for during the first few weeks after planting, very few losses should result. It is best to use balled trees as replants because such trees, when scattered throughout the orchard, can be easily handled.

## EFFECT OF FOLIAGE ON NURSERY TREES

Most California nurserymen are delivering their trees pruned back to main branches, balled, and not defoliated. If trees are to be shipped or handled under conditions of high temperature or desiccating wind, much may be said for complete defoliation of the nursery tree before it is dug. On the other hand, if trees can be handled normally without being subjected to drying out as a result of severe conditions that cause the leaves to transpire moisture faster than the restricted root system can replace it, trees with some foliage are more satisfactory.

Trees defoliated in the nursery a few days before being dug will usually push out new growth, to the limit allowed by the stored food supply, sooner than trees not stripped of their leaves; but this new growth will be shorter than that put out by the trees not thus defoliated. Trees with leaves manufacture some food, and the result is a somewhat more extended growth during the first cycle than is achieved by defoliated trees. However, the hazard of introducing orchard pests which might be carried on leaves is somewhat reduced with defoliated trees. Both types of planting have been successful, and under favorable conditions either method can be used.

## TIME OF PLANTING

In California, citrus trees can be planted from January to July, depending on the district and the method used. Trees should never be planted when they are approaching the season in which they would normally go dormant. They

should have enough growing time to put out a full growth cycle and mature it before entering the winter season.

Balled trees can be planted earlier in the spring than bare-root trees. They do not immediately need to replace completely their small feeding roots in order to put out leaves. The soil, therefore, need not be so thoroughly warmed up. Early spring planting gives the tree a period in which to rebuild its balance gradually as the weather changes and the soil warms up to growing temperatures; it will not then be subjected to the maximum strain of hot weather without time for some readjustment to its reduced and unbalanced root and top system. Commercial plantings should always be made at the best season, which for balled trees in most parts of California is during March, April, and May. In desert sections, such as the Coachella and Imperial valleys in California, where the winter heat permits growth, earlier planting, in January or February, is favored in order to get the trees established before the hot weather of late spring.

Bare-root trees should not be planted until the soil is warm and the growing season is well begun. Placing bare roots in a cold soil delays new root growth and may result in decay. Bare-root trees are therefore not planted until late April or May.

The best time for planting varies in different countries and must be determined by experience in each section. In Florida, for instance, where the main dry season begins in March and extends to the beginning of the summer rains in June, the best time to plant is in January and early February (Camp *et al.*, 1945). Early summer planting after the rains begin is also considered fairly satisfactory, if trees can be obtained in a dormant condition and a sufficient amount of water is provided.

## CARE OF NEWLY PLANTED TREES

### PROTECTION AGAINST INJURY FROM RODENTS AND PESTS

Once the orchard is set out and irrigation started, the problem of rodent and pest control becomes important (chap. xvi). Gophers and rabbits are frequently a constant hazard. Rabbits may chew the bark off a tree, causing serious injury, and even cut very small trees completely off. Rabbits are seldom a problem when trees are three or four years old. Wrapping with paper or heavy whitewashing is usually a sufficient repellent.

Gophers, and in some places field mice, are a constant hazard. Gophers migrate from adjacent uncultivated land, burrow in the ground, and may completely girdle trees underground. The injury may not be observed until it is too late to save the trees. Gophers are easily controlled by the alert grower who constantly has traps or poison ready for setting as the burrows are found. Field mice do not present a serious problem except where litter or trash is permitted to accumulate around the trunk of a tree, offering a haven and a place under cover next to the trunk that invites girdling of the tree at ground level. Mulching with straw or leaves and permitting prunings or trash to accumulate around the trunk is therefore hazardous. Moles live on grubs and insects inhabiting the soil and are not dangerous pests except as they interfere with

irrigation by burrowing across furrows and causing the water to run astray. Insect pests do not usually constitute a major problem in the first year or so. If clean nursery trees are obtained, scale control should not be necessary for some time. Aphis may cause damage to the young growth and should be controlled with nicotine sulfate spray or dust. Thrips also affect young trees in interior areas and may require treatment (chap. xiv).

## PROTECTION AGAINST SUNBURN IN ARID REGIONS

*The use of tree protectors.*—In regions of low humidity and high temperatures, trees should be given protection against sunburn as soon as they are planted. For this purpose ordinary newspaper loosely wrapped around the trunk is quite satisfactory. The wrapping material must extend from the ground up to the branches. The string or raffia used in tying the wraps should be of such quality that it will decay and break by the time tree growth has tightened them; this will prevent girdling of the tree by string that has not been cut in time.

Several kinds of tree protectors manufactured especially for the purpose are effective, comparatively inexpensive, and easily attached. Those used in California are made of thick paper or yucca wood, with attachment wires to hold them in place. They are usually fastened loosely around the tree, permitting circulation of air, and thus are less likely to cause tree girdling than tightly wrapped tree protectors which may not be properly applied or looked after.

Dark-colored wrapping material is undesirable. Unless enough space is left for ventilation, dark material may absorb heat enough to cause injury. Trees have been observed on which the bark had been killed under a dark burlap wrapping while bark exposed to the direct sun had not been injured. Where wrappers are used on trees in heavy soil, care should be exercised to prevent free moisture from collecting at the base of the tree. Infection causing gummosis has occurred under such conditions.

*Whitewashing.*—Most tree wraps will last through two years, after which protection is not usually necessary. In some localities tree wraps cannot be used, because of the haven they offer to certain ants and other insects that cause serious injury to the tree under protection of the wrap. Whitewash applied to the trunk from the branches down offers the best solution to this problem. Whitewash is not only adequate as a sunburn protection, but also acts as a repellent to insects and rabbits. Any good whitewash mixture or commercial cold-water paint can be used. (For a formula see the appendix to this chapter.)

## PROTECTION AGAINST FROST INJURY

*Protection by wrapping.*—Young trees are more subject to frost injury than old trees and thus in many sections require special protection during the first two or three years. (See fig. 109.)

Palm leaves, cornstalks, and stalks of milo maize, sorghum, and similar plants are materials which may be used. Sudan grass, planted in rows so that

it may be cut and laid on a wagon bed, later to be carried along the young tree rows and easily removed for wrapping, is satisfactory.

Where strong winds occur, it may be necessary to stake the small tree, especially after wrapping. Great care must be exercised when staking young trees not to pull the tree to the stake when tying it, as this frequently results

Fig. 169. Young navel trees wrapped with palm leaves for frost protection. Notice tree wraps for protection against rodents and sunburn, and stakes to support trees against severe wind.

in broken trees, especially if the bud union is not well healed over. Ordinary binder twine or the twine from shook bundles obtained at packing houses is satisfactory for tying trees to the stakes. When the last danger of frost is over, the tree wrapping should be removed, and if it is of such material that it can be cut up by ordinary cultivating tools at the time of spring working, it can be spread in the middles between rows, away from the trees, thus adding organic matter to the soil and saving haulage labor.

If Sudan grass or corn is grown in the orchard to provide wrapping material, it may be grown in the tree row, or in the space between rows if the orchard

is not intercropped. Such plants are heavy feeders and should be grown at a distance of at least 6 or 8 feet from the small trees.

*Protection by mounding.*—In districts where severe freezes occasionally occur, soil is often mounded high enough around the trunks to protect the bud union and part of the trunk. In the Satsuma districts of the Gulf States, trees were formerly headed low enough to permit the mounding to include the main crotches of the tree. In certain districts of Florida and Texas the most vulnerable part of the tree is the bud union, and freezing may cause girdling at that point; hence mounding has been a method of protection employed there, also.

Some hazard exists in permitting earth mounds to remain too long. If conditions develop that are favorable to fungus infection, bark decay and serious injury to the tree may result. Mounds are therefore thrown up as late as possible for protection and pulled down as soon as the frost hazard is over.

#### FERTILIZING THE YOUNG TREE

During the first summer, young trees can be fertilized with nitrogenous fertilizer; a light application in the basin around the tree, just prior to irrigation, two or three times in the course of the growing season, will usually result in better growth. One or two shovelfuls of dairy manure, free from straw, applied soon after planting, with a good mulching of similar material in the fall, will add to the tree's growth the first year. Care must be exercised to keep the manure from coming in contact with the trunk of the tree. Fertilization is especially desirable for replants in a mature orchard or in a reset orchard where the soil may be depleted.

Fertilizers are sometimes mixed with the soil in the tree holes at the time of setting the trees, but this is hazardous. Well-rotted manure well mixed with several times its bulk of soil and kept completely away from the ball or roots of the tree can be used with safety. A very light application of commercial fertilizer, especially organic materials such as dried blood and cottonseed meal, might be mixed in the soil before it is used in refilling the holes. However, satisfactory tree growth can be obtained by applying such fertilizer after planting, and this in general is the safer practice. Camp (Camp *et al.*, 1945) advises that, in Florida, a small amount of fertilizer be added to the soil around the tree, covering an area slightly larger than the basin in which roots were originally placed.

## WINDBREAKS FOR CITRUS ORCHARDS

### TYPES OF WINDS AND WIND DAMAGE

There is scarcely a citrus grower who has not at one time or another seen the results of severe wind injury in unprotected orchards, particularly in areas where the periodic desiccating winds (the so-called "desert" winds) have partly defoliated trees and blown off an appreciable amount of fruit. In southern California the damage has in large measure been prevented by the planting of miles of windbreaks, bringing into production valuable citrus lands that otherwise would be untenable for that crop (fig. 110).

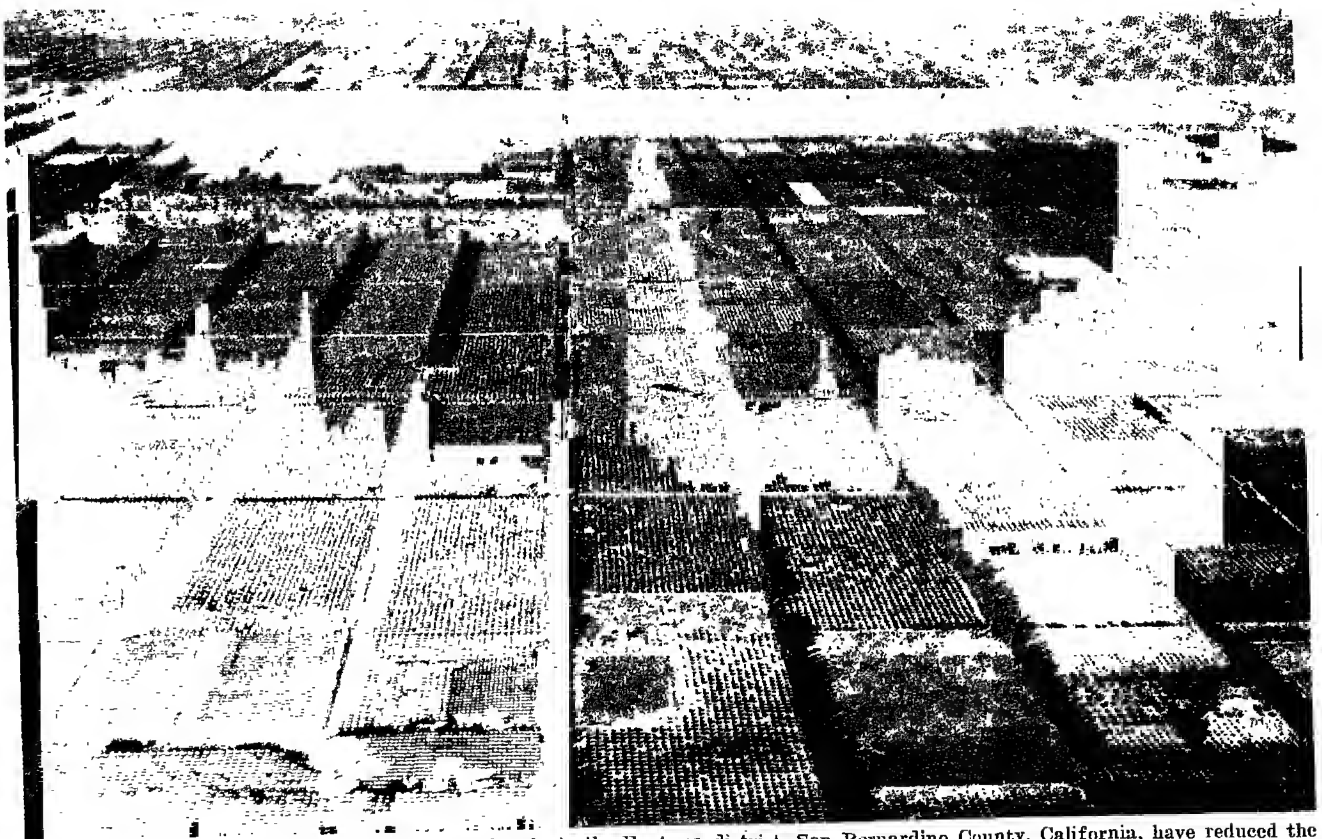

Fig. 110. Four hundred and fifty miles of windbreaks in the Fontana district, San Bernardino County, California, have reduced the average wind travel. Without these rows of *Eucalyptus globulus*, the production of citrus under the severe winds in this area would not be possible. (Photo by 23d Photo Section, Air Corps, U. S. Army.)

Early records and statements of pioneers bear witness to the violence of these storms. After windbreaks were planted, and the plantings grew in height and density, the force of the wind became much less noticeable, and in some districts it seemed that "the climate had changed." What had really happened was that the naturally recurring winds were being deflected upward from one windbreak to the next, so that ground velocities were reduced, and hence major losses were no longer suffered in horticultural crops.

Changes of ownership occurred, and the new owners, after a few years of tenancy without damage, decided that windbreaks, which reduce the yield of the outer rows of the orchard, were no longer necessary and removed them. In many places, long rows of windbreak trees have been replanted even before the trash and stumps from the old, established windbreaks cut down by new owners could be removed. The replanting has followed serious injury where the original windbreak previously had provided adequate protection.

Similar injurious winds occur in many citrus-growing regions. In some citrus areas, as in Florida, Texas, and the West Indian islands, severe hurricanes may occasionally cause great destruction. The discussion given here is limited to conditions occurring in California, but the principles involved apply to any location.

In districts where windbreaks are necessary fewer orchard trees can be planted per acre, because of the marginal space needed for the windbreaks, and because the shading by the windbreak affects both growth and production, especially to the north of a mature east-and-west windbreak row. Orchard heating may have to be started earlier, although the loss of heat through air movement should be less. If eucalyptus trees are used as windbreaks, the orchard may be reinfested by red scale, control of which on eucalyptus of the size commonly seen in windbreaks is difficult if not entirely impracticable.

*Continuous winds of low velocity.*—In general, there are three types of winds against which protection must be provided. First, there are those general winds of rather low velocity which do not affect older trees but which may blow so continuously at some seasons that young trees may be misshapen by them and "blown over" on one side. Mature trees usually have the weight and stiffness required to overcome such winds.

*Coastal winds.*—In areas along the coast, winds coming off the ocean affect horticultural crops from one to five miles inland. Their velocity is usually not great, but weather conditions where they blow, mainly the temperature, are not ideal for tree growth and fruit setting. Blanchard (1934) gives the results of fruit counts on protected and unprotected Eureka lemon trees in Ventura County, California, where coastal winds prevail (table 20).

*Winds of great velocity.*—The third type of wind is that of great strength, often reaching an average velocity of 35 miles per hour with gusts of 50 miles per hour or greater. Such winds are usually accompanied by low relative humidity and high temperature if they occur in the early fall, not entirely because they originate on the desert, but because of dynamic compression accompanying their origin (Young, 1933). They are not serious every year, but at irregular intervals.

These winds whip the trees violently, strip off leaves, break branches, and tear off much fruit. Furthermore, the fruit not torn off is reduced in value by scarring and bruising.

Even if serious mechanical injury does not result, high winds in spring or fall are sometimes so hot, and the relative humidity so low, that leaves are killed by scorching. One of the most serious effects also is the extensive killing of small twigs. Trees will put out new growth, but such growth will at first be weak, and the tree may be in poor condition for several seasons. The fruit that remains will be small and of poor quality. Growth is usually best on the lee side of the tree, making the tree unbalanced and less able to carry a good crop of fruit.

TABLE 20

INFLUENCE OF COASTAL WINDS AND WINDBREAKS ON YIELDS OF YOUNG EUREKA LEMON TREES*

| | Average number of fruits per tree | |
|---|---|---|
| | With no windbreak | With windbreak |
| Four nine-year-old trees | 97 | 710 |
| Five four-year-old trees | 55 | 288 |

* Adapted from Blanchard, 1934.

Figure 111 illustrates a Valencia tree photographed a few weeks after a severe desert wind. This is a typical example of the extreme injury that may occur rather frequently in certain citrus-producing sections of southern California if protection by windbreaks is not provided.

## EFFECTIVENESS OF WINDBREAKS

*Reduction in wind velocity.*—The effectiveness of windbreaks in protecting citrus orchards in California from damage by winds of high velocity and low humidity is well illustrated by the data given in tables 21 and 22. Table 21 gives the actual reduction in wind velocity as recorded by anemometers, and table 22 shows the segregation of fruit by grades from packing-house records illustrating the effect of windbreak protection as compared with damage to unprotected trees in adjoining orchards.

*Reduction in loss from evaporation.*—The drying power of wind is reduced in about the same proportion as its velocity. Bates (1924) states that "in the immediate lee of the most effective windbreaks evaporation is reduced as much as 65 per cent." The value of a windbreak as a protection against loss by evaporation and transpiration during periods of extremes in temperature and relative humidity has been demonstrated many times. It is not probable that serious injury would have resulted to adequately irrigated orchards under such atmospheric conditions as existed from October 16 to 18, 1935, had the seventeen-mile wind that accompanied these atmospheric conditions been reduced by windbreaks. Compare the reduction in wind velocity by windbreaks given in table 21 for November 18, 1925.

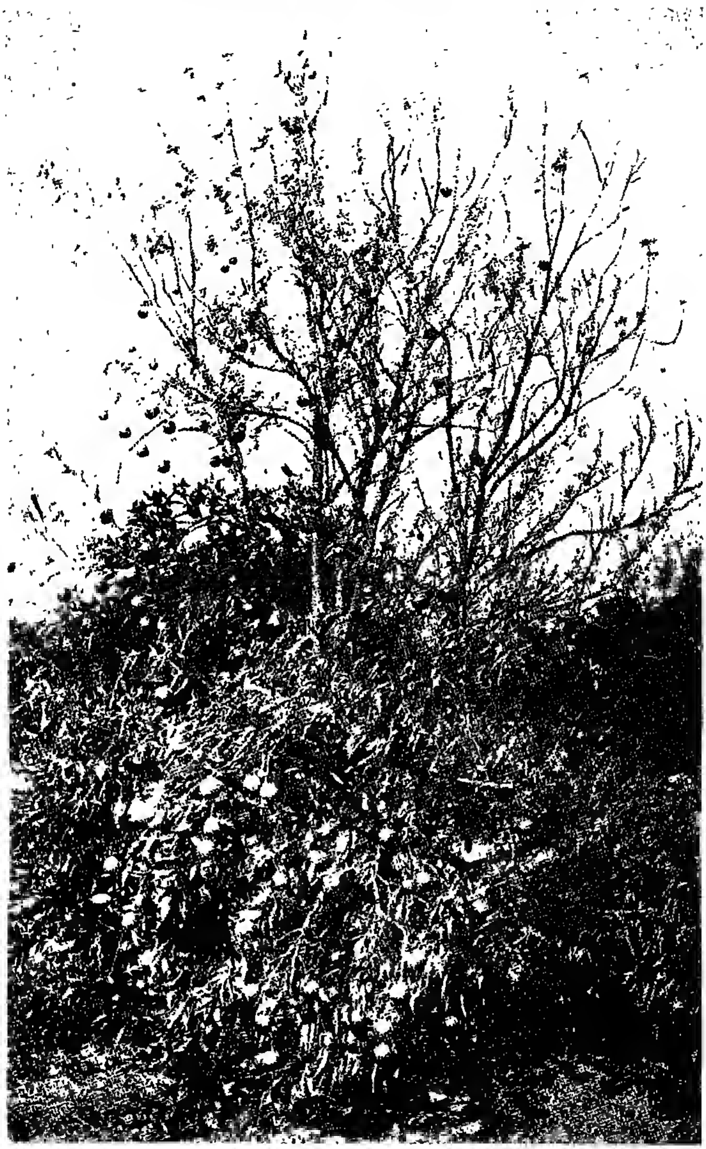

Fig. 111. Effect on a Valencia orange tree of a dry wind that defoliated its top and windward side. (From Calif. Agric. Exper. Sta. Bull. 484.)

Figure 112, from a self-recording temperature and humidity instrument at the California Citrus Experiment Station near Riverside, illustrates the extremes to which atmospheric moisture may drop. The lower line shows the

relative humidity dropping from 94 per cent of saturation—a wet, foggy condition on the morning of October 16, 1935—to a relative humidity of 12 per cent, in seven hours. The drop in humidity was accompanied by a rise in temperature from 45° F. to 80° F. and intermittent winds to seventeen miles per hour as shown by adjacent recording anemometers.

TABLE 21

WIND VELOCITIES IN THE OPEN AND BEHIND WINDBREAKS*

| | Miles per hour | | |
|---|---|---|---|
| | Average hourly | Average hourly maximum | Maximum for period |
| *November 18, 1925* | | | |
| Station in open | 12 | 15 | 27 |
| Station 165 feet behind windbreak[a] | 5.5 | 6.5 | 15 |
| Decrease due to windbreak | 54 per cent | 57 per cent | 45 per cent |
| *December 8–10, 1926* | | | |
| Station in open | 18 | 22 | 29 |
| Station 310 feet behind windbreak[a] | 8 | 9 | 13 |
| Decrease due to windbreak | 56 per cent | 59 per cent | 55 per cent |

* From Young, 1927.
[a] Windbreak made up one-half of eucalyptus (blue gum) about 95 feet high, and one-half of Monterey cypress about 70 feet high. Both the eucalyptus and the cypress were about 30 years old at the time these data were compiled.

TABLE 22

EFFECT OF WINDBREAK ON GRADE OF FRUIT*
(Per cent of each grade)

| Location of trees | Grade of fruit | | | |
|---|---|---|---|---|
| | Fancy | Extra choice | Choice | Standard |
| Protected area | 13 | 61 | 21 | 5 |
| Unprotected area | 5 | 49 | 35 | 11 |

* Adapted from Wahlberg, 1933.

This period of low relative humidity and moderately high temperatures prevailed day and night for three days, resulting in very severe leaf burn to exposed trees on the windward side. No breakage resulted; only leaf burn and young twig injury. The period of low humidity and gentle winds was followed by two days of heavy wet fogs in the early morning, then three days of winds reaching a velocity of approximately 50 miles per hour in gusts, with an average for one hour on the morning of October 23 of 38 miles per hour. This latter wind resulted in severe mechanical injury to all exposed citrus trees.

It may be questioned whether sections so windy as to require extensive windbreak plantings should be employed for citrus. A windbreak occupies a considerable part of the productive area and greatly reduces the returns per

acre—so much so, indeed, that the planting may be unprofitable. Unless other factors are sufficiently favorable to offset wind damage, sections so windy as to require extensive windbreak protection should be avoided in choosing a citrus-orchard site.

### ARRANGEMENT AND PLANTING OF WINDBREAKS

*Windbreaks as part of the producing area.*—Windbreaks, where vitally important, are being developed as part of the producing area. They are irrigated, fertilized, and handled with equally as good management as the citrus

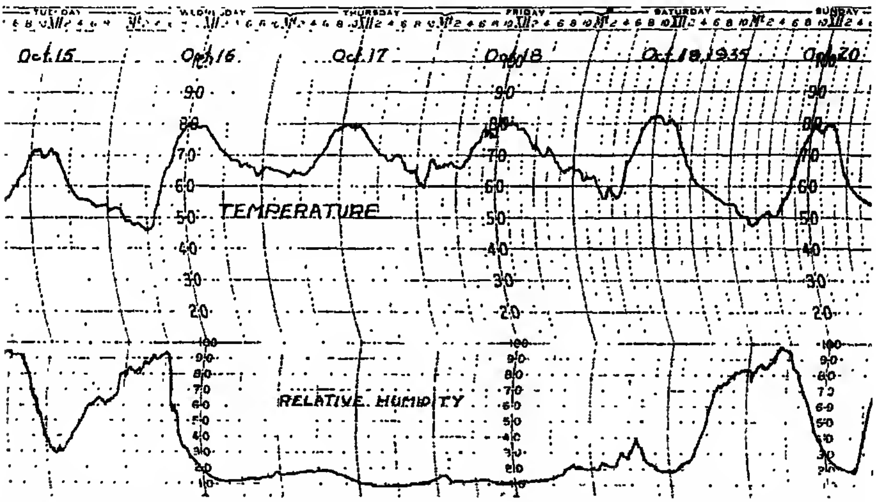


Fig. 112. Temperature and relative humidity recorded at the Citrus Experiment Station, Riverside, California, October 15–20, 1935. These atmospheric conditions accompanied light winds, causing no mechanical injury to the trees. Note low humidity night and day.

part of the plantings. A windbreak does not, of course, produce fruit; but if it affords such protection to the adjoining citrus trees that the yield per acre is increased, as compared with unprotected groves, it is proper to consider it an essential part of the producing area.

*Permanent windbreaks.*—Permanent windbreaks should be planted, if possible, two or three years before the citrus, so that protection will be available as soon as possible. Many varieties of trees are available for windbreaks, but only those varieties should be considered which are suitable to the climate and soil conditions and which, if possible, are not affected by insects and diseases attacking citrus. A good windbreak tree must be upright in growth and occupy as little space as possible, tall, mechanically strong, rapid-growing, and of a density sufficient to offer the necessary resistance to the prevailing winds.

In areas where frost is a hazard and orchard heating is not practiced, it may be desirable to use a somewhat open type of tree. This permits breezes or air currents to flow through and thus reduce the cold pockets resulting from poor air drainage. If orchard heating is practiced, it is more desirable

to have a dense windbreak, especially if the cold is likely to be accompanied by a breeze which so dissipates the heat that orchard heating is inefficient.

Some species of trees used for windbreaks may extend their roots for food farther than others do—even several tree rows into the orchard. Root cutting next to the citrus trees must then be done once or twice a year, with deep-subsoiling tools and specially constructed root-pruning equipment. The windbreak must also have ample irrigation and fertilization, so that the trees will make the best possible growth with minimum extension of the root system.

*Distance between windbreaks.*—Practical experience and the use of self-recording anemometers have shown that windbreaks placed about 300 feet apart are adequate to protect most orchards. Table 21 illustrates the results from placing anemometers 165 feet to the leeward of a 95-foot windbreak, where a 45 per cent decrease in wind velocity was recorded with a wind which reached 27 miles per hour, and 55 per cent at 310 feet with winds of 29 miles per hour. Similar results were recorded by Wahlberg (1939) for such distances, but with only a slight reduction at 500 feet to the leeward side of a mature windbreak.

Ordinarily, winds of an average velocity of 20 to 25 miles per hour will not do serious damage unless accompanied by an extremely low relative humidity and a very high temperature. A wind with a velocity of even 45 miles an hour might be so reduced by a good windbreak as greatly to lessen the damage to a mature citrus orchard. Windbreaks every 300 feet more or less would be necessary to cope with winds of such average velocity.

*Windbreaks and property lines.*—In many localities the planting of windbreaks has come to be more or less a community or district project. Because the protection is needed, and the windbreak management has been well conducted, little conflict has arisen between neighbors over property rights and root extension. However, it is well to insure permanency of the windbreak by planting it well within the property line, thus providing adequate root space and anchorage if adjoining property requires the cutting of encroaching roots. Entering into an agreement with owners of adjoining property for permanent protection of the windbreak may be desirable (R. L. Miller, 1936).

When planting is done beside highway rights of way, consideration must be given to future pipe lines, power-line poles, and street-widening activities. Most county road departments have definite regulations governing the location of utilities and trees for different road right-of-way widths. These regulations should be carefully considered before planting, in order that, as far as can be determined, no conflict of windbreak and future utility installations will result.

*Selection and planting of seedling trees.*—Only trees of normal growth, medium size, and well-developed root systems should be used. Small young trees 6 to 10 inches high that have not been checked in their growth by the container in which they were planted are most desirable. The method now most generally employed is to grow the seedlings in some kind of temporary deep paper pots, about 2½ to 3 inches in diameter by 6 to 8 inches deep. Trees grown in such paper pots or other small containers to a height greater than

10 or 12 inches are too often partly potbound—a very undesirable starting condition for a tree that is to withstand the effect of strong winds. Trees 8 inches high in flats 2 to 3 inches deep, hardened off for transplanting, give most satisfactory results. Trees much taller than this are undesirable. The small trees can be cut out and planted with the square of soil surrounding their roots. They seldom, if ever, have curled roots when grown in shallow flats and transplanted at that stage of growth.

Removing well-grown trees from flats by cutting out a square of soil containing the roots seldom checks the growth of the young trees, if they are not subjected to too severe conditions the first few days after transplanting. Such trees planted early in the spring just as the normal growing season starts will have a long growing season ahead of them. With proper care and management they should enter their first winter in the best condition to resist the winds that may be as severe upon them their first year as upon citrus.

Where the climate is severe, or where winds blow before the small trees are well started, a shingle set at an angle to protect the small tree from wind and sun, and from soil movement that would cut the tender stem, is necessary. If the small tree is not sufficiently irrigated and protected, a row that is irregular in density may result. It is necessary that all trees come up together, as it is extremely difficult to fill in a gap by replanting.

*Planting distance.*—If a single row of trees of one variety is to be set, the trees should be planted 5 or 6 feet apart. If a tall-growing type is to be used, such as the blue gum (*Eucalyptus globulus*), interplanted with a shorter but dense type such as the Monterey cypress (*Cupressus macrocarpa*), they are set as alternate trees, those of the tall variety being placed 10 or 12 feet apart. A double row may be desirable, in which event the rows should be 5 to 6 feet apart, with the trees in one row opposite the spaces in the other row.

*Pruning the windbreak.*—Every effort should be made to promote and retain growth near the ground. The windbreak should be uniform in density from the ground up, and no pruning should be done that would tend to reduce the density of the tree or remove limbs that cannot be replaced.

With eucalyptus such as the blue gum it may be desirable to cut the top out of the tree when it has reached a height of 6 feet. By use of the pruning shears about a foot of the central leader is removed. This stops the very rapid initial growth, which is usually rather spindling, and causes the tree to stiffen up and mature its growth. It also tends to promote lateral branching near the ground. If the trees are well cared for and growing vigorously, the cutting results in only a temporary cessation of growth and will result in much better root development and more mature tops to stand the first season's winds. If the trees are making an unduly vigorous growth, a second topping may be necessary when the trees reach a height of 8 to 10 feet. Vigorous growth is desirable even though topping has to be resorted to.

Where double rows of blue gum have been planted close together, it is frequently desirable after a few years to prune back severely every other tree, or every tree in one row. This will cause vigorous growth to come out low down on the tree, thus replacing branches at the lower levels which have been

shaded out or lost from other natural causes. Trees are often planted somewhat closer together with this object in view.

TREES USED FOR WINDBREAKS IN CALIFORNIA

*Eucalyptus globulus* (blue gum).—The blue gum is one of the most satisfactory windbreak trees employed in California. It is a rapid grower, structurally strong as a mature tree, and deep-rooted. It is tall and reasonably narrow in its spread as compared with its density. Figure 110 (p. 285) illustrates a well-managed single-row windbreak of blue gum, showing its density near the ground and, because it has been regularly root-pruned, irrigated, and fertilized, has had a minimum effect on the adjoining Valencia orange trees.

The blue gum is not a satisfactory tree in the desert areas of California, such as the Imperial and Coachella valleys, where extremely high temperatures and low humidity prevail. It is also somewhat susceptible to injury by low temperatures where conditions are such that it may not go as dormant even as citrus. Temperatures of 15° F. may seriously injure *Eucalyptus globulus* if the trees are not in complete dormancy or if such temperatures prevail for any length of time.

*Eucalyptus globulus compacta* (bushy blue gum).—A new variety of the blue gum is now being tried because of its low, compact growth, which develops densely enough to stop the wind from going through the windbreak at ground level. It is used as an interplant in rows of *Eucalyptus globulus.*

*Eucalyptus viminalis.*—If the conditions are unfavorable for *Eucalyptus globulus,* the Manna gum (*Eucalyptus viminalis*) may be used. It is not so tall a grower in relation to its breadth and is to be considered as only a substitute for the blue gum where the latter species cannot be grown.

*Eucalyptus rudis* and *E. tereticornis.*—These are species generally unsatisfactory for windbreaks except where *E. globulus* or *E. viminalis* cannot be grown. However, in areas of continued high temperature and low humidity, such as in the Imperial and Coachella valleys in California, they serve satisfactorily if a eucalypt is desired. For general use, no eucalypt tested thus far has proved so satisfactory for a windbreak as *E. globulus.* Most species are mainly either too broad-spreading, too brittle, or too open in their type of growth.

*Cupressus macrocarpa* (Monterey cypress).—This species was formerly widely planted as a windbreak, especially in coastal areas of California, but because a fungus disease, Cupressus canker (*Coryneum cardinale*) has caused severe tree loss, its use has largely been discontinued (Wagener and Dimock, 1943). *Cupressus Forbesii,* a species believed to be more resistant to Coryneum infection, has been trial-planted in some districts. Eucalyptus species, however, especially the blue gum, have proved so satisfactory in most districts that they have quite generally been used instead of cypress. The degree of resistance of other species of cypress to Coryneum infection has not been fully determined, but apparently they are not so susceptible as the Monterey cypress (Wolf, 1939; Thompson, 1939).

*Cupressus arizonica* (Arizona cypress).—This species can be substituted for the Monterey cypress where the latter is not adapted. It is not satisfactory, however, and has not been widely planted for this purpose.

*Casuarina stricta* and *C. equisetifolia*.—These species of Australian trees, though not frequently seen, may make satisfactory windbreaks if very dense and tall trees are not desired. They are light feeders, and evidence is available to show that they have nitrogen-fixation powers similar to legumes (Mowry,

Fig. 113. Athel (*Tamarix articulata*) windbreak protecting young grapefruit in the Imperial Valley.

1938, p. 29). They do not grow so tall and dense as the blue gum and are not such rapid growers.

*Tamarix articulata* (Athel).—This desert tree from northern Africa is admirably adapted to desert growing conditions (fig. 113). It is easily propagated by cuttings and, if an abundance of water is available, makes very rapid growth where hot, dry weather prevails. It cannot be classed as a drouth-resistant tree, since it demands heavy irrigation under the prevailing high temperatures of desert sections. It is a dense, rapid-growing tree reaching a height of 45 feet in a few years. The principal objection to the Athel tree is that it is a voracious feeder, extending its roots to distances several times its height into the adjoining cultivated area. It therefore demands the best in cultural practice and windbreak management if it is not to deplete several rows of the adjacent orchard it is protecting.

*Oleander and sour oranges*.—These have sometimes been employed where low windbreaks were desired, but owing to their great susceptibility to insect infestation they are not satisfactory. Palms also have been used, but do not

fulfill the density requirement and are rarely employed except where an ornamental effect is wanted.

No attempt is made here to discuss all the trees and shrubs that could be employed as windbreaks. The species best adapted to a certain section may not be satisfactory under different environmental conditions. Growers who find it necessary to use windbreaks should be mainly guided in their choice of species by the local experience available.

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# APPENDIX TO CHAPTER V

A formula for whitewash (Woglum, 1937) which has been satisfactory with respect to reflection of light, adhesiveness, ease of preparation, and low cost, as well as possible stimulative effect, developed for spraying defoliated trees but adaptable to brushing, is as follows:

| | |
|---|---|
| Hydrated lime | 50 lbs. |
| (Any good grade may be used; dolomite sticks well.) | |
| Zinc sulfate | 4 lbs. |
| Water | 100 gals. |
| (These materials may be introduced directly into the spray tank.) | |

The addition of one-third pint of liquid blood albumin spreader improves the adhesiveness of the mixture.

Zinc Bordo (5 pounds) may be substituted for the zinc sulfate, with comparable results.

Stone lime may be used, but is more troublesome to prepare since it must be slaked and allowed to cool outside of the spray tank.

In whitewashing the trees, the pressure should be reduced below 300 pounds and a No. 9 disk used.

The amount of water should be reduced if the material is to be applied with a brush.

# CHAPTER VI

# CULTIVATION, OR TILLAGE

BY

WARREN R. SCHOONOVER and LEON D. BATCHELOR

MUCH HAS BEEN SAID and written about the importance of cultivation, or tillage,[1] in the production of various agricultural crops, and numerous investigations have been carried on to measure the effect of cultivation on yields. Nearly all the experimental work has been conducted with annual crops, such as small grains, vegetables, and corn, the prime importance of cultivation in the preparation of a good seedbed for the favorable establishment of annual crops being generally acknowledged. The large amount of practical experience and research with annuals cannot, however, be applied directly to orchard crops; for whereas the roots of the annual crops become established to some degree in the surface soil that is tilled in preparation for the growth of the crop, the roots of orchard trees are mainly below the tilled zone, or are destroyed by periodic tillage if they grow into this zone. The orchardist is therefore confronted with the problem of determining just how much and what type of tillage is essential for tree crops.

Some of our tillage practices are the outgrowth of customs developed under conditions very different from those now obtaining, a point well brought out by Russell and Keen (1938, p. 212): "Cultivation methods were developed in the days when horses or oxen were the only sources of motive power. Except at the busiest times of the year, some men and horses would be free, and when circumstances permitted it was natural to use them on the land in the belief that if an operation improved the appearance of the soil the crops must benefit. Hence there may be two kinds of cultivation operations, those essential for good crops and those that are really spare-time occupations. Many of the latter have become merged in the body of agricultural tradition, so that it is not now possible without experiment to distinguish between essential and subsidiary operations. Two important features of modern arable farming are the rapid rise in the cost of agricultural labour . . . and the partial replacement of the horse by the tractor. To enable the wage scales to be paid the output per man must be increased and the cost of cultivation reduced as much as possible."

It may therefore be profitable to omit some cultivation operations even if yields are slightly reduced. All citrus growers should give thought to the necessity of each and every cultural operation. The procedure adopted will vary greatly with the natural conditions—the character of the soil, rainfall, prevalence of weeds, and other local factors. It may be well always to keep in mind that the functions of cultivation, and of the surface soil, may be very different in an established orchard from what they are where annual crops are grown.

[1] The terms cultivation and tillage are used interchangeably throughout this chapter.

Citrus is grown in environments varying widely with respect to soil, climate, and economic conditions. It is therefore entirely impractical even to attempt to recommend a tillage procedure for citrus orchards in general. There are extremely gravelly soils in some California orchards, where any tillage of consequence is futile. There are extremely sandy soils in Florida, and to a less extent in California, where little tillage is needed. There are other soil types, especially the Ramona and Placentia loams in some California orchards, where tillage is needed but, if excessive, is harmful to the soil structure. This, in turn, may have an adverse effect upon the infiltration rate of irrigation water and rainfall, and it is to be remembered that slow moisture infiltration is often a factor in causing soil-erosion problems even in orchards of only moderate slope. On the other hand, there are deep friable soils where tillage may be essential and relatively harmless.

Thus the widest possible variety of cultivation practices may be found in orchards equally successful. Or there may be no cultivation at all. In fact, several practical, localized systems of orchard management have been developed, both in Florida and in California, that do not involve cultivation or tillage. In this chapter, therefore, the principles involved in the cultivation of orchard soils are dwelt upon, rather than definite recommendations, which will naturally result from local experience.

A discussion of tillage in relation to the production of citrus fruits might well be limited to a statement of the most common unfavorable conditions that can be overcome by soil-stirring operations, and to a description of effective methods of conducting them. It is necessary to consider soil-stirring in an orchard as possibly having observably harmful aspects, as well as beneficial aspects. The purpose of each tillage operation should therefore be appraised carefully in relation to conditions existing in the orchard at the time the operation is contemplated. If the probable benefits to be derived are not likely to exceed the possible damage sufficiently to justify the expense, the operation should be omitted.

## PURPOSES OF CULTIVATION

The principal purpose of cultivation is to create a more favorable environment for the plant, with respect to moisture supply and availability of the nutrients supplied by the soil, than would prevail if such operations were omitted.

The relative effectiveness of cultivation in attaining these objectives will vary with the season, the character of the soil, and the nature of the crop (Baver, 1940). In orchards on some soils, cultivation will increase the rate of infiltration of water, especially at the beginning of an irrigation period or during the first few hours of a heavy rainfall; in orchards on very sandy or gravelly soils, this is not an important consideration.

Since weeds compete with trees for both soil moisture and nutrients, such competition is important, especially in rather infertile soil and in seasons of low rainfall, and the elimination of competitive weed growth becomes one of the prime objects of cultivation.

Briefly, the aim of cultivation in an orchard is to control weed competition and to aid in keeping the soil in a state of good tilth. And soil tilth, according to Russell (1938, p. 34), "has often been defined as something every farmer can recognize but no scientist can describe. . . . Originally the word was used in sentences such as 'the soil is in tilth for ploughing.' . . . Tilth in present-day farming language is probably more connected with the condition of the seed-bed than with the condition of the land at the best time for ploughing." This implies, in part at least, that the soil which is in good tilth is the surface layer of a few inches, and that this is the soil which is going to be occupied by the roots of the primary crops grown on the land. With orchard trees, however, most of the roots are below the zone of soil commonly thought of as in good tilth, and the soil of the lower horizons may be in good tilth for the welfare of the trees when the surface soil is not considered to be in that condition. Extreme examples can be seen in soils which, although so rocky on the surface that tillage is futile or very nearly impracticable, are nevertheless satisfactory for the growth of citrus trees.

According to Baver (1940, p. 291): "Tilth is commonly defined as the physical condition of the soil in its relation to plant growth. This definition includes all those soil conditions that determine the qualities of the soil as a suitable physical environment for plant growth. It is obvious that soil-structure relationships constitute a major portion of this physical condition. Adequate aeration, sufficient moisture, ready infiltration of rainfall and so forth are functions of good tilth."

*Control of weed competition.*—Investigators are now convinced that the principal value of cultivation is to kill weeds and thereby reduce the competition for both soil moisture and plant food, rather than to create a dust mulch to prevent loss of soil moisture by capillary movement.

Prior to 1910 it was the belief of many investigators and of numerous farmers that the forming of a dust mulch by cultivation was an effective means of conserving soil moisture. The theory was that when the surface soil is loosened by cultivation the particles of soil are removed from close contact with each other and the films of moisture around them lose most of their water by evaporation, the break in the compactness of the soil column preventing the capillary movement of moisture to the surface of the ground. The dry layer of loose soil was thus considered more effective than undisturbed soil in checking evaporation.

The capillary movement of soil moisture from a free water surface was fully demonstrated in the early experiments (King, 1904; Fortier, 1909); the movement without the presence of such a water table was not demonstrated. It is readily understandable, nevertheless, in view of these early experiments, why a dust mulch was erroneously considered an effective means of conserving soil moisture under average arable conditions. It seems clear now that a dust mulch would be effective only when there is a high water table within capillary reach of the surface of the soil—a condition so rarely found in citrus orchards that it need not be considered here. Some of the earliest studies to indicate the futility of cultivating to create a dust mulch for the conserving of moisture,

with no water table present, were carried on with agronomic crops and with plants grown in watertight cylinders.

It was found at the Nebraska Experiment Station (Barker, 1912, p. 110) that the loss of water by evaporation from the surface of the soil is very small after the moisture reaches an equilibrium, and that "the loss takes place mostly when the surface soil is very wet, before the moisture is thoroly distributed thruout the soil, and before the soil is in a good tillable condition." This was confirmed by additional experiments carried on during 1910 and 1911 at the same experiment station (Young, 1912, p. 128), from which it was concluded:

"1. That a loose soil mulch was not much more effective than an unmulched soil in retarding the evaporation of the moisture that is well established in the soil.

"2. That if a hard layer of soil dries out to the depth of two or three inches, it will act in the capacity of a mulch.

"3. That much more of the established soil water is lost thru transpiration from the leaf surface of plants than is lost by evaporation from the soil surface."

These results were confirmed by subsequent experiments (Alway, 1913; Burr, 1914; Miller, 1916) on the growth of various plant roots in relation to soil moisture. For example, Burr (1914, p. 76) concluded that "the plant roots, to obtain water, extend themselves into the soil zone where available water is present, rather than depend upon the water being brought to them by capillarity."

Extensive experiments were carried on in Kansas from 1909 to 1916 on both dry-farmed and irrigated plots (Call and Sewell, 1917, p. 61), from which it was concluded: "A cultivated soil is no more effective than a bare uncultivated soil in preventing evaporation. . . . The development of nitrates may be as extensive without cultivation as with cultivation." These results, plus those in Nebraska (Young, 1912), aroused the initial doubts concerning the value of the cultivated dust mulch as a means of conserving soil moisture.

Another pioneer experiment carried on at the same time was designed to measure the effect of cultivation on crop production in Illinois. Under the conditions existing in this experiment (Mosier and Gustafson, 1915), it was shown that the yields of corn were as heavy when the weeds were killed without stirring the soil as when they were killed with ordinary shallow cultivation.

Subsequent investigations with respect to citrus orchards in California (Schoonover, 1924, 1927, 1930*a*, 1930*b*, 1936), Florida (Chase, 1929), and Texas (Friend, 1933), and with respect to orchard cultivation in general (Veihmeyer and Hendrickson, 1928, 1930), have confirmed the principles brought to light by the earlier studies. The competition between weeds and trees occurs from the time the roots of the weeds reach down far enough to intermingle with the roots of the trees. Competition from even relatively shallow-rooted weeds and grasses is important in citrus orchards, with their rather shallow-rooted trees. Even in soils 4 or 5 feet deep, the soil-moisture extraction, and thus the apparent root development, have been shown to be mostly in the first

3 feet of soil (Beckett, Blaney, and Taylor, 1930), with more than 60 per cent of the roots in the first 2 feet.

Competition between weeds and trees may be for moisture or nutrients, or both. The seriousness of the possible competition for moisture is indicated by the data in table 23, which show that during a period of approximately three and one-half months water consumption in a weedy plot of a mature orange orchard exceeded that in a clean-cultivated plot of the same orchard by approximately 5 acre-inches, or 28 per cent. (See also chap. x, this volume.) The weeds in the experimental area started to grow on May 1 and grew vigorously until they were turned under on August 12, when they were very large.

TABLE 23

COMPARISON OF WATER CONSUMPTION IN WEEDY AND IN CLEAN-CULTIVATED ORCHARD PLOTS, 1930*

(In acre-inches)

| Plot | May | June | July | Aug. 1–12 | Total |
|---|---|---|---|---|---|
| No. 1. Weedy | 3.3 | 7.0 | 8 0 | 5.0 | 23.3 |
| No. 2. Clean | 2.5 | 5.4 | 6.0 | 4.4 | 18.3 |

* Data from a mature orange orchard near Redlands, California. Compiled from records of S. H. Beckett, Professor of Irrigation, University of California Citrus Experiment Station.

There seem to be no quantitative experimental data available covering the magnitude of competition for nutrients in citrus orchards. Field observation indicates that such competition may be very severe, especially during the period of blossoming and maturing of weeds or cover crops. The relative importance of weed competition for moisture and for plant nutrients in the cornfield, in Illinois, was shown by Wimer and Harland (1925, p. 174). After conducting experiments for nine years, these authors concluded: "The principal object and greatest value of corn cultivation on Brown Silt Loam is the destruction of weeds. Weedy corn probably suffers more from a lack of nutrients than from a moisture deficiency in this climate. Since cultivation is the only practical method of controlling weeds, the depth and frequency of corn cultivation should be determined by their growth. The growth of weeds should be prevented in so far as possible by shallow rather than by deep cultivation."

The amount of weed growth allowable in an orchard before competition justifies the expense of a tillage operation will vary with the fertility of the soil and with the cost of fertilizer and of irrigation water, or with the prospective rainfall in districts where irrigation does not occur. Small weeds or scatterings of large weeds are not of practical importance. Large weeds may not be harmful during the semidormant period of the trees. It rarely pays to have a weed-free orchard, for the amount of tillage required is likely to be too expensive, and the detrimental effects on soil structure usually more than offset the gains.

It should be pointed out that while control of weed competition is usually accomplished by some sort of tillage or soil-stirring operation, it may be accom-

plished by mowing or pasturing, or by the use of a herbicide, such as oil spray. Mowing and pasturing are considered impractical in a citrus orchard. The use of oil as a spray is still in the experimental stage; it seems to have some promise at present, however, as a substitute for very shallow hoeing to eradicate small weeds long before they become competitive with the trees. (See "The 'Hinckley System' of Noncultivation," p. 318, below.)

*Preparation of soil for water.*—In districts where citrus trees are irrigated, the distribution of water is usually controlled by furrows, dikes, basins, or contour checks. Since the construction of these works requires loose soil, a soil-stirring operation becomes necessary to facilitate control of water application. This applies to orchards cultivated periodically as a matter of routine procedure, but not to orchards managed according to the so-called "Hinckley system" of noncultivation (see p. 318), or to the relatively few citrus orchards that are in permanent sod. The same furrows, dikes, and so on, may be used for more than one irrigation, but they will have to be renewed from time to time, and cultivation will be necessary. If removal of excess surface water is also considered a factor in proper distribution, such means as contour furrows and terraces may also be required for removal of excess water during the rainy season.

With respect to water penetration, from either irrigation or rain, a tillage operation may or may not be useful, its value depending on the natural character of the soil and the condition of the surface soil. Salter (1940), in his excellent résumé, mentions the detrimental effect of puddling or compaction that takes place under some conditions and reduces the pore space in the soil. Occasionally, this puddling and the reduction of pore space in a thin layer at the surface will have a detrimental effect on moisture penetration or on the aeration of the entire profile. The immediate effect of proper tillage operations on some soil types is increased moisture penetration. The tilth of the surface layer is usually of less importance with a permanent crop, however, such as citrus trees, than in a seedbed prepared for an annual crop. The long-time effect of tillage in orchards, if carried to excess, is often the formation of a compacted layer that interferes with the maintenance of satisfactory conditions in the root zone. This subject is more fully discussed later in this chapter.

*Incorporation of fertilizers.*—Manures and other bulky organic fertilizers are most effective if mixed with a relatively thin layer of surface soil. If applied as mulches, they are subject to losses of nutrient material and interfere with the usual orchard operations. In orchards of the semiarid regions, mulches are also a fire hazard. Bulky organic fertilizers are therefore usually incorporated into the soil by some soil-stirring operation such as plowing or disking. Under most conditions it is good practice to mix cover crops, as well as bulky fertilizers such as manure, with the surface soil to promote decomposition. If any of these materials are worked too deeply into the soil, however, tree roots are likely to be cut, with detrimental effects offsetting, to some degree, the beneficial effect of the fertilizer.

Applications of manure in trenches 12 inches deep proved less effective, over a period of years (Parker and Batchelor, 1942), than applications broad-

cast and disked into the soil to a depth of approximately 5 inches. Much of the ineffectiveness of the trench method of application was apparently due to the repeated annual cutting of the roots of the orange trees.

Soluble fertilizers, particularly nitrogenous compounds, are usually applied on the surface of the soil, to be carried in by rain or irrigation water. With these fertilizers, cultivation is unnecessary.

*Preparation of soil for cover crops.*—For the purposes of this discussion, cover crops may be divided into two classes: those with small seeds that are sown directly on the surface of the soil, and those with large seeds that should be covered when planted. With the small-seeded cover crops, such as the several species of mustard and the various species of clover, which are to be planted on the surface of the soil, it will be necessary to disk or harrow the soil to a depth of only 2 or 3 inches before furrowing or otherwise preparing the land for irrigation. The seed is then sown, after the furrows are made and immediately before irrigating. (See "Cover Crops," chap. viii.) With cover crops having larger seeds, such as bread beans (*Vicia Faba*), it is desirable to cover the seed by disking or by cultivation, after which the land may be furrowed and irrigated. All cover crops will germinate and grow best if planted in a soil of reasonably good tilth. Preparation of the seedbed and subsequent covering of the seed, provided this is done, require tillage operations that cannot be omitted.

*Incorporation of cover crops.*—When first turning cover crops under, it is not necessary to break up the material completely in order to incorporate it in the soil. Figure 114 shows satisfactory initial disposal of a cover crop by going over the land once with a cover-crop disk. It will be necessary to go over the land again before furrows or basins can be made for distribution of water, but leaving the chopped-up crop on the surface of the soil, or only partly covered, as suggested above, results in a better soil condition and a better rate of water infiltration than more thorough incorporation. This procedure also lessens the possibility of the soil's becoming puddled by the dashing rains that are likely to follow the disking.

The beneficial effects of the cover crop on soil structure should not be offset by the use of improper tillage operations in turning it under. The orchardist confronted (1) with the necessity of destroying the cover crop so that it will no longer compete with the trees for soil moisture, and (2) with the necessity of incorporating it into the soil so that it will decay and leave the surface soil in such condition that following rains will infiltrate rapidly, and so that the land may subsequently be prepared for irrigation, seldom completely incorporates the cover crop into the soil during the initial disking.

*Promotion of aeration.*—Under some conditions, aeration of the soil may be retarded by a thin crust and may be improved by a crust-breaking operation. Such conditions seem rare in California citrus orchards, however. The net effect of a large number of tillage operations, over a period of years, is usually interference with aeration in the root zone through the gradual development of compacted layers just below the cultivated zone. (See "Harmful Effect of Cultivation," p. 308.)

*Cultivation and other orchard operations.*—Certain useful purposes accomplished by cultivation really have little if anything to do with the soil management. For example, if an orchard is irrigated in basins, or by furrows made diagonally across the tree rows, traffic lanes will have to be cultivated and leveled to permit hauling of fruit and passage of spray rigs. Where fumigation is used as the means of scale control, it is necessary to have an even soil surface for the operation of tent-pulling machines and as a means of securing

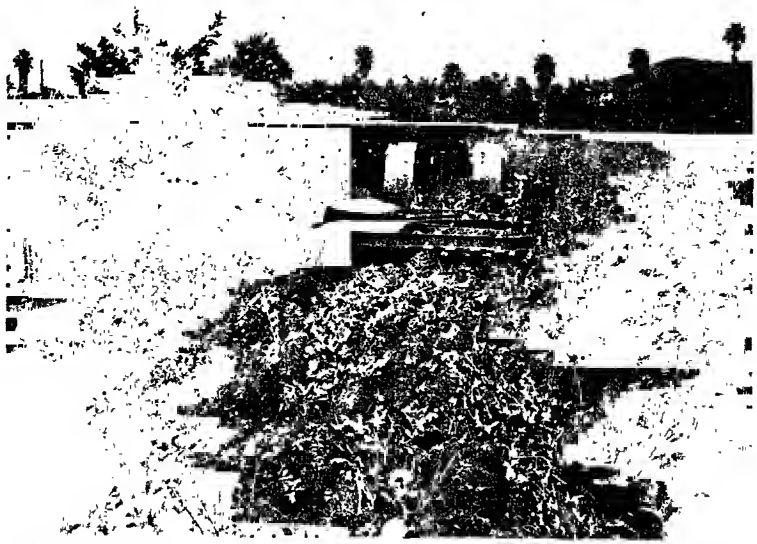

Fig. 114. Satisfactory initial disposal of a cover crop by going over the land once with a cover-crop disk.

proper contact between the ground and the fumigation tents to prevent the loss of poisonous gases. It is therefore necessary to smooth over the furrows or *basins by proper cultivation.*

Where permanent cover crops are used for erosion control, and competition is reduced by mowing, thick mulches develop and become a fire hazard. The best way to overcome this hazard periodically is to mix part of the material with the soil by disking. Other useful functions of cultivation will occur to orchard operators as they study particular problems.

## HARMFUL EFFECTS OF CULTIVATION AND TRAFFIC ON SOIL STRUCTURE

*Harmful effect of cultivation.*—The effect that cultivation has on the physical condition of the soil depends on several factors, especially the original physical character of the soil, its chemical nature, and the relative amount of

moisture present in the soil when it is cultivated. It can probably be accepted as a general rule, however, that almost all soils are of a better structure for plant growth and are more porous and more easily tilled when they are first cleared from the virgin state than after they have been cultivated for a few years. The preservation of a favorable soil structure comparable to that of the virgin soil should, so far as practicable, be the objective of all orchardists.

The effect of cultivation on the soil has been reviewed by Russell (1938, p. 20), who comments, in part, as follows:

> The effect of cultivation implements on the soil can be considered from two aspects, namely, their effect on the distribution of aggregates and on the distribution of pores. Further, the effect of the implement on the soil structuro is very dependent on the moisture content of the soil at the time it is worked. The correct basis for the interpretation of this dependence has only recently been found, although it is a problem of fundamental importance to all practical cultivators....
>
> Each type of implement has its own individual action on the soil structure, and this action is dependent on the soil moisture content. If the soil is worked at a moisture content not very much drier than that for optimum structure formation, ploughs, cultivators and rotary cultivators all have much the same effect on the soil aggregates: they may either break an aggregate into a few smaller ones or make a few aggregates form a single one, but in general only very few aggregates smaller than ½ mm. are produced. But if the soil is drier than this the distinction between crumbling an aggregate into several finer ones along lines of weakness in the original aggregates and shattering the aggregate becomes important, for the latter procedure typically results in the production of fine dust, i.e. particles or aggregates passing a ½-mm. or finer sieve. Under these conditions the difference between the mouldboard plough and the cultivator or rotary cultivator becomes marked....
>
> In conclusion, cultivation operations can undoubtedly increase the amount and the stability of the aggregates present in a soil provided a suitable implement is used when the moisture content falls within a certain fairly narrow limit. If the soil is cultivated when much drier the general effect of cultivation is to reduce the amount of aggregation. This seems to explain why the main characteristic of cultivated soils in the arid and semi-arid regions is their poorer and weaker aggregation as compared with the virgin soils.

The fact that excessive cultivation with any sort of tool can have a particularly harmful packing effect on soil structure should be more generally appreciated. It would be a good axiom never to stir the soil unless there is certain to be a useful effect that more than offsets the possible accompanying damage to soil structure. The possible harmful effect of too much cultivation was recognized early in the development of horticulture in California. Investigators of soil problems associated the aeration of soils by cultivation with certain persistent changes in soil structure which were taking place in the State. This was deplored by Hilgard (1906, p. 131), who wrote: "That excessive aeration results in serious losses of humus as well as of nitrogen, is very obvious in the arid region, where it is the habit to maintain on the surface of orchards and vineyards during the dry, hot summers, a thick mulch of well-tilled soil, thus preventing loss of water by evaporation. In the course of years this surface soil becomes so badly depleted of humus that good tilth becomes impossible, the soil becoming light-colored and compacted; while the loss of nitrogen is indicated by the small size of the orchard fruits."

Baver (1940, p. 292) says: "Tilth is a dynamic, not a static soil condition. The tilth of a given soil tends to deteriorate under the usual cropping and tillage operations. Good tilth may be renewed through the use of sod crops in the rotation and suitable tillage methods." The use of cover crops and bulky organic fertilizers is usually the most practical way to renew good tilth in citrus orchards. (See "Cover Crops," chap. viii.)

The most common type of impairment of soil structure occurring in citrus orchards is the development of a compacted layer, called the plow sole, just

TABLE 24

SOIL COMPACTION (PLOW SOLE) AT VARIOUS DEPTHS IN CULTIVATED AND UNCULTIVATED AREAS OF A NUMBER OF SOUTHERN CALIFORNIA CITRUS ORCHARDS*

(Uncultivated areas are of soil beneath branches of trees)

| Location of sample | Volume weight | | Weight in pounds per cubic foot | | Percentage of pore space | |
|---|---|---|---|---|---|---|
| | Cultivated soil | Uncultivated soil | Cultivated soil | Uncultivated soil | Cultivated soil | Uncultivated soil |
| | Ramona soils (average) | | | | | |
| Surface soil | 1.57 | 1.41 | 98 | 89 | 41 | 47 |
| Upper sole | 1.80 | 1.52 | 112 | 95 | 32 | 43 |
| Lower sole | 1.61 | 1 46 | 100 | 92 | 39 | 45 |
| Subsoil | 1.57 | 1.37 | 98 | 85 | 41 | 48 |
| | Hanford soils (average) | | | | | |
| Surface soil | 1.40 | 1 27 | 88 | 79 | 47 | 52 |
| Upper sole | 1.65 | 1.50 | 103 | 93 | 38 | 43 |
| Lower sole | 1.56 | 1.43 | 97 | 89 | 41 | 46 |
| Subsoil | 1.36 | 1.34 | 85 | 84 | 49 | 49 |

* Data supplied by Charles F. Shaw and G. B. Bodman, Division of Soils, University of California, Berkeley.

below the cultivated zone. In a study of plow sole in a number of southern California citrus orchards, Shaw and Bodman[1] compared the condition of the cultivated soil with that of the uncultivated soil beneath the trees. Results are summarized in table 24. These data clearly indicate the degree of soil compaction at four different depths, as measured by increased volume weight, weight per cubic foot of soil, and percentage of pore space. It is apparent that cultivation and traffic have had a decidedly injurious effect on the structure of these soils. The loose mulch in the cultivated areas was about 6 inches deep. A careful examination of the colloid content showed no evidence of an accumulation of fine particles in that part of the profile which was directly below the cultivated zone. It was concluded that the plow sole was due to compaction probably caused by the combined effect of cultivation and traffic in the orchard, especially that which took place while the layer was still wet enough to be plastic.

[1] Charles F. Shaw and G. B. Bodman, Division of Soils, University of California, Berkeley. Unpublished data.

A similar condition was found[1] in another citrus orchard, also on Hanford gravelly sandy loam, at Claremont, California, where the average weight per cubic foot of the soil beneath the mulch in an area subject to traffic and cultivation, between trees, was 125 pounds; and of the soil of the same horizon in an area not subject to cultivation for many years, under the tree branches, was 91 pounds. Figure 115, *A*, shows the compacted soil from the cultivated area of this orchard; *B*, soil from the same horizon of the uncultivated area.

Parker and Jenny (1945) studied the effect of traffic and of disking on the rate of water infiltration and the soil structure in both wet soils and dry soils. The rate of water infiltration in these soils was greatly reduced by both operations, as compared with that in undisturbed soil. The damage to soil structure was greater with wet soil than with dry soil, however, and the increase in volume weight extended more deeply into the soils worked over when wet than into those worked over when dry. These investigators thus showed that tillage and traffic greatly increased the volume weight and impaired the permeability of the soil. They also showed that water penetration subsequent to these harmful operations was improved materially by letting the soil go through a period of several years without any tillage.

Striking effects have been observed in southern California citrus orchards as a result of reducing tillage operations to a minimum. In one Orange County orchard on Yolo loam, the rate of water infiltration increased twelvefold as a result of reducing tillage operations from an average of twelve to fifteen diskings a year to only two diskings annually. Similar, less striking results occurred in an orchard on Hanford gravelly sandy loam, near Pomona, California, where the rate of water infiltration was increased fourfold by greatly reducing cultivation. The ameliorating effect of reduced cultivation is not fully understood, because it may occur with or without the growth of weeds or cover crop.

The destructive effects of tillage on soil structure are not limited to the soils of the irrigated regions of the Pacific Southwest that are low in organic matter. Soils relatively high in organic-matter content, such as Porterville adobe, are also affected. A similar relation between tillage and soil structure has been reported in Oregon orchards (Stephenson and Schuster, 1942). In West Virginia, an experiment by Sudds and Browning (1941) indicated that cultivation reduced the organic-matter content, the percentage of the larger-sized soil aggregates, the noncapillary porosity, and the infiltration rate, but increased the volume weight and the dispersion ratio. A more general understanding of the detrimental effects of tillage will lead to a more reasonable program in most orchards.

A few fallacious beliefs, as in the value of a dust mulch or the harmful effect of a few weeds, have encouraged excessive tillage, which in past years has been detrimental to the soil structure in many orchards. Tillage does not conserve moisture in an amount of any consequence in a relatively weed-free soil (see "Control of Weed Competition," p. 303, above).

[1] Unpublished data supplied by Dr. Esther P. Perry, Division of Soils, University of California, Berkeley, 1941.

Fig. 115. The effect of traffic on the composition of the soil in a California citrus orchard: *A*, compacted soil from an area subject to traffic and cultivation, between trees; *B*, soil from the same horizon of an area protected from cultivation, beneath the tree branches.

A dust mulch is not advantageous to soil structure. Some citrus growers have been misled by noting that deeply cultivated areas in an orchard will remain moist longer than those not cultivated, even though there are no weeds

and moisture is being extracted only by the roots of the trees. The condition noted results from the fact that deep cultivation cuts the tree roots which would utilize the moisture. That kind of tillage does conserve moisture, but not for beneficial use. In a nonirrigated almond orchard cultivated to a depth of 14 inches, it has been observed that the layer from the 4th to the 14th inch remained moist all season because the tree roots were for the most part cut back. The trees were severely damaged by the deep cultivation, and the moisture conserved was of no use because the trees could not get it.

The effects of tillage on aeration of orchard soils have also been misunderstood. Aeration, as well as water penetration or permeability of a soil, depends upon the large pores, or the so-called noncapillary pore space. One of the main effects of tillage on the zone just below the loose mulch is a reduction in the noncapillary pore space. This is especially hastened if the soil is worked when it is too wet. Compaction of the soil in the zone below the cultivated area is also increased by the passage of wagons, trucks, and heavy tools when the soil is wet, and to a less degree when dry. Some of this traffic may be unavoidable, but every effort should be made to reduce it as far as is practicable.

A comparable effect occurs in the cultivated mulch itself, if the soil is broken down to a dust. The tillage practice of creating a dust mulch has probably made a notable modification in the soil structure in many orchards: it has reduced the noncapillary pore space and the rate of water infiltration in the respective orchard soils, in comparison with the original conditions of these soils. Some intermediate practice can usually be followed, between that of allowing the weeds to grow freely over prolonged periods and that of cultivating so excessively that a fine dust mulch is maintained.

*Harmful effect of traffic.*—Traffic over the soil in citrus orchards is detrimental to good soil structure. Some traffic is essential to carry on the tillage, however, and some is necessary for other operations such as hauling fruit, distributing orchard heaters, hauling fuel for heaters, disposing of brush, and moving spray rigs, dusting equipment, and fumigation tent-pulling devices through the orchards. Orchard heating and spraying are emergency operations and often cannot be avoided even though the soil is very wet and obviously will be badly puddled by the traffic, the principal effect of which is to pack the soil to a dense consistency and in large measure to destroy the original structure.

The deleterious effects of traffic can be overcome only partially by any sort of tillage operation. Subsoiling and chiseling, which are practices commonly used for this purpose where annual crops are grown, are not very effective, and the harmful effect of cutting tree roots precludes the practicability of using such methods with orchard crops. Moreover, the operations of subsoiling and chiseling merely break the soil into blocks without increasing the pore space, and afford only temporary relief by permitting greater water penetration in the cracks between the blocks, which soon consolidate. Taylor (1934) has proposed a special system of tillage and irrigation that would confine the traffic of trucks and tractors to the same locations in certain interspaces. The suggestion is made that the soil in such traffic lanes be left undisturbed and

that what might be called normal cultivation operations be confined to the rest of the orchard.

Orchards on heavy soils present a serious problem in the hauling of heating oil for refueling. In California the occasional cold nights necessitating orchard heating occur in winter, when rains are periodic and the soil may be so muddy and soft that oil-tank wagons and trucks have difficulty in carrying out the emergency task of refilling. This situation has been met in one large lemon orchard by making a road of coarse gravel (fig. 116) in every fourth interspace throughout the orchard. Such roads serve not only for hauling fuel, but also for hauling out fruit. Inasmuch as lemons are picked eight to ten times each year, the use of these roadways avoids a great deal of soil packing in the rest of the orchard. The favorable moisture distribution beneath the gravel road is shown in figure 117.

## COMMON TILLAGE PRACTICE IN CALIFORNIA AND ARIZONA

The majority of citrus orchards in California are disked at least once a year, usually in the early spring, at the end of the rainy season, for the purpose of incorporating a cover crop or volunteer weed crop into the soil. Where cover crops are not grown and organic matter is added to the soil by the use of manure, bean straw, or other bulky materials, the usual procedure is to disk after these fertilizers have been applied. Few orchards are cultivated to smooth over the surface soil after the spring disking. At the beginning of the irrigation season, however, it is sometimes necessary to disk again at a shallow depth to cut up the organic trash in the surface soil before making the furrows, basins, or dikes for irrigation.

During the first two decades of the present century the general rule was to cultivate once, twice, or even three times after each irrigation, as soon as the soil was dry enough to work without puddling it. Much of this useless and in fact harmful cultivation has long since ceased, and most orchards are now cultivated only once after an irrigation, or once after every other irrigation. The common practice is to reduce these operations to the barest necessity, to prevent excessive weed growth during the irrigation season. The actual number of cultivations per year will vary considerably and will depend on the time intervals between irrigations, the character and fertility of the soil, the amount of shade, and thus the amount of weed growth in the orchard, as well as on other local considerations.

Summer cultivations are usually done with a spring-tooth harrow, or with a light-weight disk harrow. If the disk harrow is used, measures to prevent too deep cultivation are advisable. The common means of preventing this harrow from cutting too deep is to equip it with rollers between the disk blades, as illustrated in figure 118. The rollers can be designed in sizes to let the disk into the soil at any desired depth. In some extremely gravelly sandy-loam orchard soils, cultivations have been reduced to two or three per year. The average number of cultivations will be more nearly five or six per year, including the disking to incorporate organic matter into the soil and the preparation of the seedbed before sowing the cover crop in the fall.

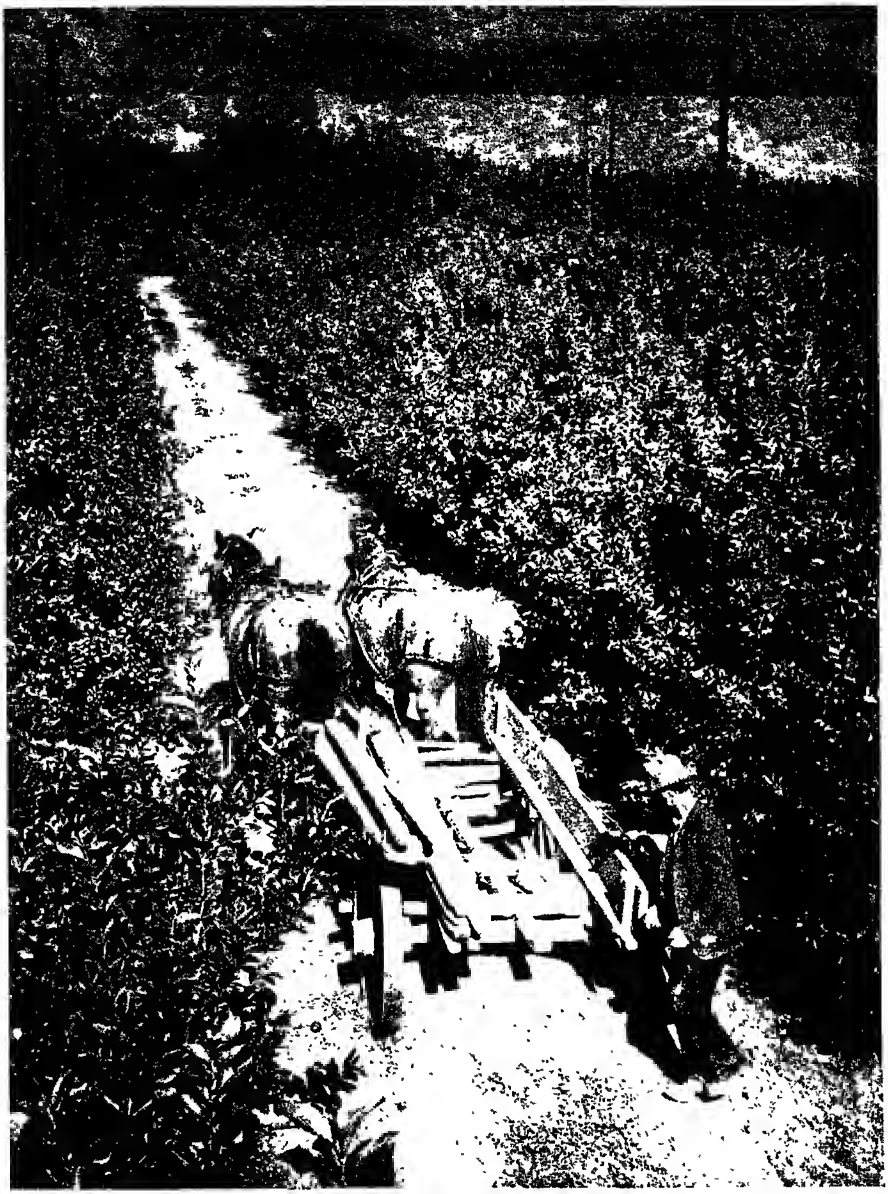

Fig. 116. An all-weather roadway consisting of a light covering of coarse gravel over the soil. Similar roadways were made in every fourth interspace throughout this lemon orchard.

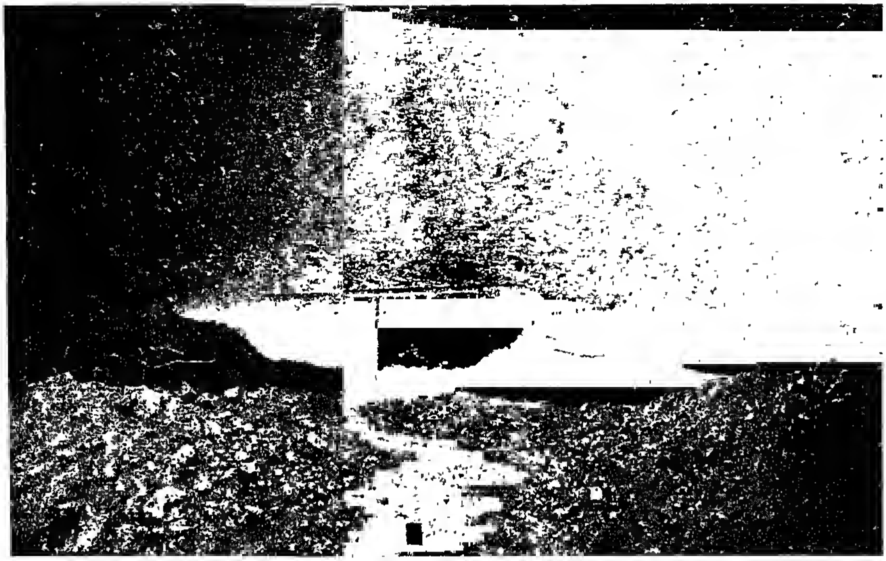

Fig. 117. Soil-moisture distribution beneath gravel road shown in figure 116. Maximum depth of dry soil (light area) is 22 inches.

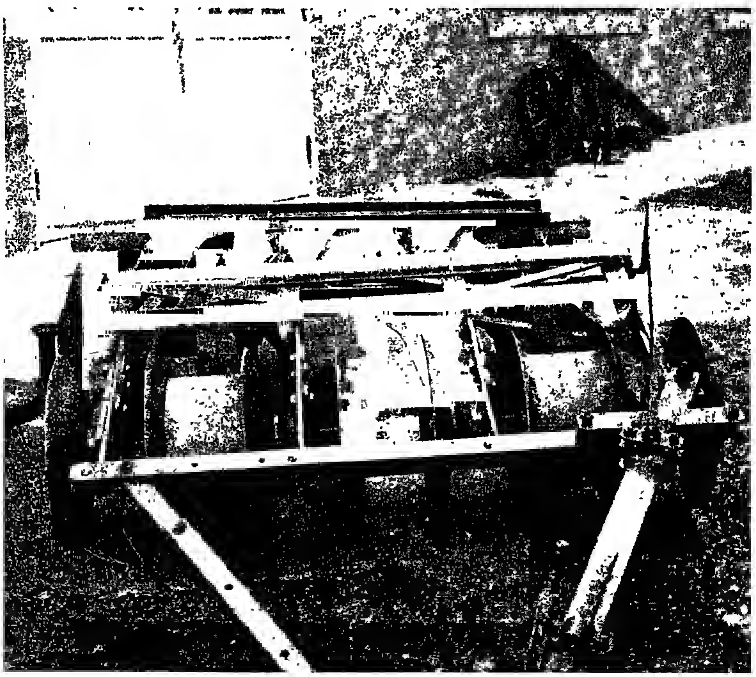

Fig. 118. Roller attachments between blades on disk harrow, to prevent deep tillage.

The usual tillage procedure in the desert citrus areas of California and in orchards in Arizona differs, in seasonal operations, from that in the coastal districts of California. In the first-named districts, an abundance of irrigation water makes it practical to grow summer cover crops. Since the winters are nearly rainless and some winter irrigation is necessary, some orchards produce a winter cover crop in addition to the summer crop. The tillage in these areas is therefore largely determined by the culture of the cover crops and their incorporation into the soil. The disk is the principal implement used in such orchards, aside from the various tools used to prepare the land for irrigation.

## COMMON TILLAGE PRACTICE IN FLORIDA

Orchard tillage in Florida has passed through much the same evolution as has occurred elsewhere. During the first two decades of the century, emphasis was placed on maintaining a weed-free orchard whenever no cover crop was growing. This required a great deal of cultivation, and the dust mulch was considered a prerequisite to good culture. As experience broadened under various conditions in the state, the justification of so much expense for cultivation was more and more brought into question, especially as it became known that various orchards which were being cultivated less than normally for the respective districts and for the decades mentioned were satisfactory producers of high-class fruit.

One of the first references to the extreme practice of noncultivation in this country was that made in a paper read before the Florida State Horticultural Society by the owner of a successful ten-year-old orchard who had planted it without even first clearing the pine trees from the land (Stevens, 1921, p. 122): "This first grove having done so well, we set other groves among the pines, in every case thinning out the pines to some extent because we thought the first grove had too many in it. In none of these groves have we done any plowing, or harrowing, either before or after we planted the trees.

"In our older groves that have been plowed for years, we have adopted the same practice of noncultivation. We now fertilize and do nothing more. We mow as often as it is necessary to keep the grass and weeds from making seed."

Subsequent to the experience reported above, emphasis was placed on cultivating to only a shallow depth, and the desirability of using "spools" on disk harrows to prevent deep cultivation was indicated (Leonard, 1922). Sound advice was given by Lenfest (1924, p. 69): "Cultivation should never be done just to keep someone busy. There should always be some definite reason for working a grove and whenever possible the cultivation should accomplish more than one thing." This writer also directed attention to the impairment of fruit quality by excessive cultivation late in the growing season and strongly advocated a reduction in cultivation as the fruit approaches maturity.

It has been pointed out by Grossenbacher (1924) that, in Florida, the practice of noncultivation is best adapted to the richer soils associated with the low, damp orchard sites; it is not well adapted to the "high pine land" that is poor and perhaps short of moisture through part of the year. For the poorer

soils he recommends a limited cultivation system to avoid excessive weed competition and expresses the opinion that old bearing groves on high pine lands could profitably install irrigation systems to supply water during the dry periods. He also points out the association of excessive cultivation with stimulated fruit growth and poor fruit quality and the association of limited cultivation with improved fruit quality.

The reduction in cultivation gradually brought about in Florida, together with the use of summer cover crops, has apparently resulted in savings in operation costs and improvement in fruit texture, and has maintained the trees in good condition. (The pertinent factor of proper fertilization, which has been operative concurrently and has had an effect on fruit quality, is treated in chap. vii, this volume.)

## THE "HINCKLEY SYSTEM" OF NONCULTIVATION

Tillage of orchards in California has been reduced to a minimum where the "Hinckley system" of noncultivation (Hinckley, 1939) has been adopted. This system makes use of the same irrigation furrows year after year, and all weed control is accomplished by lightly hoeing or scraping the surface soil when small weeds start to grow. Otherwise, the soil remains undisturbed. The occurrence of weed seeds in the orchard is also reduced by using only concentrated inorganic fertilizers. The citrus leaves partly fill in the wide, shallow furrows, and accumulate under the trees; except for this, the land is bare the year round. An orchard in excellent condition, in which the Hinckley system is in use, is shown in figure 119. The shallow furrows shown in the foreground were made approximately eight years before the picture was taken. A modification of this system is in use in a few orchards where the practice of spraying the weeds with a light oil (Pacific specification 200, or Domestic fuel No. 3) is a substitute for hoeing. This modification is still in the experimental stage.

In orchards that have been fertilized with manure, and that have soil heavily infested with weed seeds, the instituting of the Hinckley system will be very laborious. This is especially true for young orchards that do not provide shade enough to suppress weed growth; in them, it may be necessary to hoe at two-week intervals, or to supplement the hoeing with oil spraying for a short while after adopting this system of noncultivation. With the passage of time the labor involved in the control of weeds in this system becomes gradually less. Few weed seeds are introduced into the orchards, and the bare ground is not a favorable seedbed for their growth. Chemical control of noxious perennial weeds with material other than spray oil is not entirely satisfactory in most orchards, because of the danger of damage to the trees.

## POWER FOR TILLAGE OPERATIONS

Power for tillage may be supplied by horses, mules, or tractors. All such necessary orchard operations can, however, be accomplished by the use of light tools that can be pulled by a team of horses. The work cannot, of course, be done so quickly as with a tractor; but in a small orchard horses or mules sometimes supply the cheapest power, particularly where the orchardist has

uses for the work animals aside from their use in tillage, as in the hauling of oil, bulky fertilizers, and fruit, and in other farm operations. The size of the enterprise, and limiting conditions such as the soil type on which the orchard is planted, should be carefully considered by the grower in choosing his source of power. The use of teams will probably be more practical on sandy friable soils than on heavy soils. In the smaller citrus orchards in some dis-

Fig. 119. Orchard maintained by the "Hinckley system" of noncultivation. The shallow furrows partly filled with leaves were made approximately eight years before the picture was taken.

tricts, a rather large amount of the tillage is performed by contractors using motor-driven tractors as a source of power, but some contract work is still done with teams.

## CULTIVATION COSTS

In the years when excessive cultivation was the rule in most citrus orchards, annual costs of tillage often ran as high as $50 per acre. In 1926, about three years after the beginning of educational efforts in California to make clear the advantage of reducing tillage operations, average annual cost of these operations in Orange County orchards (Wahlberg, 1935*a*) was about $22 per acre. There was a gradual reduction in costs in the same area to a minimum of a little over $10 in 1934, with some of the more profitable Valencia orchards showing lower cultivation and furrowing costs than the average of the group as a whole. In an analysis of the production costs for Valencia oranges in Orange County (Wahlberg, 1935*b*), the ten most profitable orchards showed

cultivation costs of \$8.13 per acre; the average of all orchards was \$10.93 per acre, and the range for this charge was from \$4.09 to \$44.24 per acre. Since 1934, costs have been rising a little, owing to increased rates of pay for labor and materials. In some California orchards, however, where the regular Hinckley system is used, cultivation costs have been as low as \$6 to \$8 per acre.

The cost of weed control by oil spraying varies widely, the cost depending on such factors as the initial infestation of noxious weeds at the time this system of culture is started and the amount of shade in the orchard that tends to suppress weed growth. Weed control by either hoeing or spraying, in any noncultivation practice, is much more expensive the first few years than after the practice becomes well established, partly because, when cultivation ceases, the seedbed for weed seeds becomes progressively less favorable. When all factors are considered, it is readily understood how the cost per acre for weed control by spraying can vary from approximately \$8 to nearly \$60 per acre, depending on the circumstances (Sullivan, Moore, Johnston, and Wahlberg, 1944).

If the citrus grower will keep in mind the limited number of useful things that can be accomplished by tillage, and the fact that such operations not only increase production costs but almost invariably have some harmful effect on soil structure, he can no doubt develop an effective and economical program for his orchard. In most orchards the purpose of tillage is primarily weed control and the disposal of cover crops and secondarily the preparation of the soil for irrigation. These objects will determine the amount of work to be done, the season in which it is to be done, the tools to be used, the depth of cultivation, and other practical considerations. The amount of work required in different orchards will vary with natural conditions, the age of the orchard, fertilizer practice, and other factors influencing the growth of weeds and the tilth of the soil.

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## Chapter VII

# PRINCIPLES AND METHODS OF FERTILIZATION

BY

LEON D. BATCHELOR

THE GENERAL SUBJECT of orchard fertilization has many ramifications with respect to materials to use, methods of application, season of application, most economical sources, and most economical amounts to use. Fertilizing a citrus grove is an investment. It has not been reduced to an exact science. When a farmer fertilizes a grove, he is acting upon a probability; he spends money for fertilizer materials on the probability that the resulting increased crop yield will repay the expended money and show an additional return. The materials purchased should be those which experience has shown are likeliest to return the greatest profit per dollar expended. The largest gross returns per acre, however, may not mean the greatest profit per acre, in proportion to money spent for fertilization, as the relative profitableness may follow the "law of diminishing returns."

The chemical elements essential for plant growth number at least fifteen, and probably more. Their origin under natural conditions is as follows:

*a*) From the solid portions of soil come calcium, magnesium, potassium, phosphorus, iron, sulfur, manganese, and traces of others, such as boron, copper, molybdenum, and zinc.

*b*) Directly or indirectly from air come carbon, hydrogen, oxygen, and nitrogen.[1]

The first group of elements listed are among those which form a high proportion of the earth's crust.

The main purpose of this chapter is to discuss the principles that determine the proper fertilization of a citrus orchard. It is not practical for a general treatise on the subject of fertilizers to give specific recommendations, since these will greatly depend upon such factors as the soils, the age of trees, past practices, local experiences, such climatic factors as rainfall, and many other considerations which will influence the action taken in a particular orchard.

## SUPPLEMENTING THE FERTILITY OF THE SOIL

Fertilizer is used merely to supplement the fertility of the soil. The chemical elements which in certain soils are in some measure deficient for the optimum growth and yield of the trees may be supplied by additions of materials containing the elements needed, or by spraying on the plants suitable compounds of the elements, as, for example, of copper, zinc, and manganese. It must be obvious that fertilizing soils to supplement deficiencies of elements is not comparable to feeding a balanced ration to livestock. It is impossible by the application of fertilizers to establish rigidly or to maintain any preconceived

[1] The nitrogen supply in the soil, except for the usually small amount in the nitrate form, is stored in the organic fraction of the soil.

notion of a balanced plant-nutritional condition. The reaction of the components of fertilizers with soils will vary greatly with the soil types and prior fertilizer treatments. Furthermore, if it were possible to maintain a definite balanced nutrient solution in the soil, provided one could be safely prescribed, there is no evidence to show that the condition of balance is essential. From a consideration of experiments on this subject it was concluded (Hoagland, 1919) that there is insufficient evidence to prove that a plant requires, for optimum yield, any very specific ratio of ions or elements within wide limits, provided the total supply and concentration of essential elements are adequate.

It is fortunate indeed for the farmer that fertilization does not mean the necessity of adding to the soil all the elements needed by the plant. The majority of them occur in adequate amounts in most of the agricultural soils. Fertilizers, in general, are essential merely to supplement supplies already present, so that crops may be grown profitably

As a general rule, in supplementing soil deficiencies, one should purchase the fertilizer materials that contain the most of the desired fertilizer elements for the money expended. This cannot always be done, however, and there is no uniform fertilizer treatment that can be prescribed for all citrus-growing areas. Differences in soil conditions, previous treatment of the orchards, impurities in the irrigation water, climatic conditions such as rainfall, and the economics of each situation must all be considered.

## SOILS OF HUMID AND ARID REGIONS

Before proceeding to more specific problems in the use of fertilizers, we may properly consider the general differences between soils of the humid regions as compared with those of the arid regions.

Soils of the arid regions are in general consistently higher in lime, magnesium, sodium, phosphate, and potash. Soils of the humid regions have been leached for countless ages by heavy rainfall, while the rainfall of the semiarid sections penetrates, on the average, only to shallow depths in the soil.

Formerly, it was thought that the plant foods most commonly lacking in soils were nitrogen, phosphorus, and potassium. Infertile soils, deficient in all three of these elements, are rather commonly found in the humid regions; hence they are the elements usually applied in commercial fertilizers. Fertilizers that contain all three of them have erroneously been considered as completely supplying the lack, and are spoken of in the fertilizer trade as "complete" fertilizers. Actually, of course, they are far from being so nearly complete as to supply all the essential elements for plant growth.

"Complete" fertilizers may merely "complete" the list of needed elements in an infertile soil deficient only in the elements they supply. Nitrogen alone, or phosphate alone, may "complete" the fertility of other soils so that profitable crops may be grown. On the other hand, there are large areas where it is becoming a common practice to apply nitrogen, phosphate, potash, magnesium, manganese, and copper to complete the fertility of the soil for citrus trees. Since there are large soil areas that are deficient in boron, and others deficient in sulfur, for general farm crops, there is a question whether nitrogen, phos-

phorus, and potassium are really the elements most commonly deficient. Deficiency does not always imply a low total supply in the soil, but may mean that certain plants growing thereon are unable to obtain enough of one or more of the particular elements to meet their growth requirements. Hence, applications of such materials in forms that are available for plant growth will result in increased crop production.

Deficiencies in three to six of the elements mentioned above are frequently noted in humid regions. In the arid regions of the southwestern part of the United States, soils are rarely found that are considered to be deficient in more than three of them. Some of the soils of the humid sections not only lack nitrogen, phosphorus, and potassium, but are also deficient in available calcium, magnesium, boron, copper, zinc, and manganese. Nearly all soils of the arid southwestern United States contain abundant supplies of available calcium and magnesium. The irrigation waters of the arid areas also contain important amounts of magnesium as well as calcium.

This brief discussion of soils of arid and humid regions should suffice to indicate that experience in fertilization gained in the humid sections may not be directly applicable to soils in arid sections; and the converse is also true.

## THE NEED OF FERTILIZATION

No definite age can be set at which a young orchard will need to be fertilized. Eventually, however, citrus groves on almost all soil types must be fertilized if they are to produce profitable yields consistently. Citrus trees growing on most soil types will reach a decadent condition if they are not fertilized, and the fruit production will become nil. A decadent orange tree is shown in figure 120. In contrast, the tree shown in figure 121 is healthy and produces from 300 to 400 pounds of oranges each year.

Some soils are naturally more fertile than others, but it seems to be only a question of time before unfertilized orchards—with very few exceptions—become unprofitable. Perhaps the two most important factors in citrus fertilization are the original differences in soils and the prior fertilizer treatment of the land. In some orchards it has been desirable to fertilize the soil when the trees were set out; in others the yields have been satisfactory without applying fertilizer for as long as ten years or more after planting. Fertilizers are now used in citrus districts throughout the world and, in general, the fertilizer bill is the largest single item of expense making up the total annual cultural cost of production.

Obviously, exactly the same fertilizer program is not equally desirable or profitable on all soils. In humid regions the rains may carry the readily soluble fertilizing materials below the root zone, and much of the fertilizer residues may then be removed in the drainage waters. In arid or semiarid regions, on the other hand, soluble substances may accumulate in the surface soils. In many orchards in the arid regions there are surface accumulations of nitrates and of other salts during the dry season. In short, both climate and soil have a bearing upon the proper methods of application, the efficiency, and the duration of the effects of fertilizers.

## GROWTH OF COVER CROPS AS AN INDEX OF FERTILITY

Something about fertilizer requirements of citrus trees may be learned from the growth of cover crops in orchards. Many annual crops, for example, are

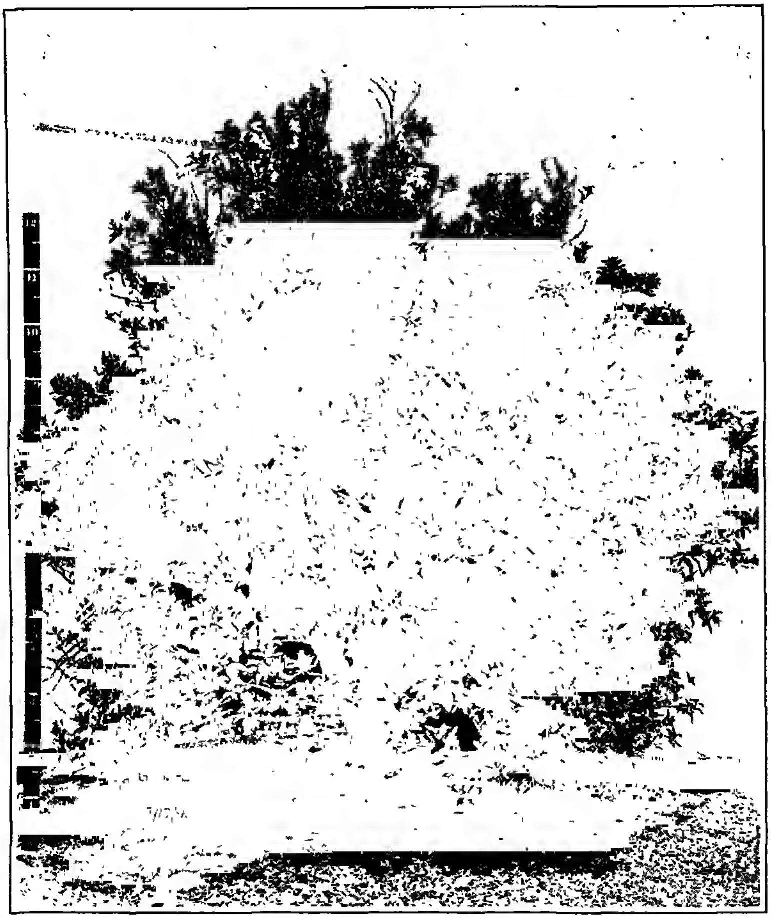

Fig. 120. Twenty-five-year-old orange tree that has never been fertilized. Compare with figure 121.

relatively heavy feeders upon potassium, calcium, and phosphorus compounds. In general, where leguminous crops thrive, the indications are that the soil is well supplied with these elements in available forms. In some humid regions, where calcium compounds have been leached from the soil, good crops of legumes cannot be grown until lime has been applied; this condition does not generally prevail, however, in citrus groves, and often legumes will not thrive as cover crops in citrus orchards, regardless of soil conditions, on account of

shade cast by large trees and competition from weeds in a well-fertilized soil. It should be borne in mind also that different crops on the same or similar soils may vary widely in their nutritional requirements. For example, fertilizer experiments with annual crops cannot always be taken as a safe guide

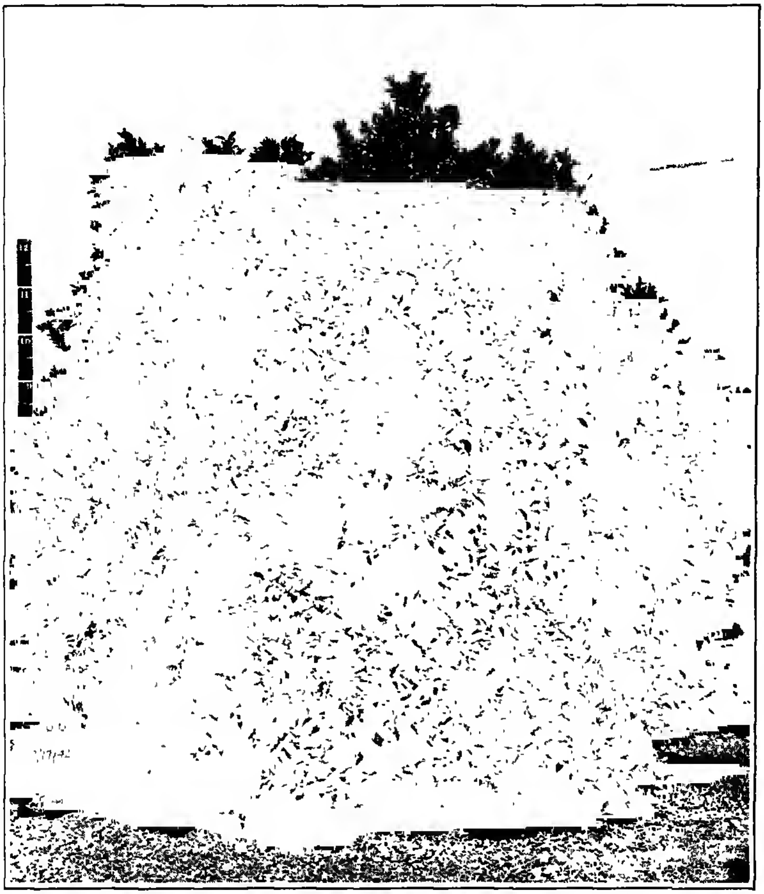

Fig. 121. Twenty-five-year-old orange tree that has been well fertilized during the past thirteen years. Compare with figure 120.

for the requirements of tree crops grown on the same soil. Again, cover crops growing on soils low in available phosphate are likely to show a striking response to phosphate fertilizers, yet it is improbable from past observations that tree crops in the same soil would show a response to phosphate even when applied in large amounts.

This principle has been illustrated (Chapman, 1934) in pot cultures on the comparative responses of alfalfa and young citrus trees to phosphate fertilizer. The production of alfalfa grown on soils low in phosphate was increased

manyfold by the use of phosphate fertilizer. On the contrary, young citrus trees grew well in the unfertilized pots and showed no measurable increase in growth in the pots fertilized with phosphate.

## BASE EXCHANGE AND FERTILIZERS

It has long been known that a process called "base exchange" which takes place in soils has an important bearing upon the action of fertilizers. In a chemical sense, a "base" is a substance capable of combining with an acid and thereby forming what chemists term a "salt." For example, sodium nitrate is a salt formed by the union of the base sodium hydroxide with nitric acid. Calcium is the base of calcium or lime compounds, potassium of potassium compounds such as potassium sulfate, and so on. Under certain conditions some bases are able to replace other bases or to change places with them. An illustration is given in the following description of a method of softening water.

The hardness of water, which is due to an excess of the bases calcium and magnesium in solution, is removed by passing the water through a water-softening material containing sodium in an adsorbed and exchangeable form. An exchange takes place; that is, the calcium and magnesium in solution take the place of the adsorbed sodium, the latter passing into solution in an amount more or less equivalent to the combined calcium and magnesium content of the original water, depending on how completely it is softened. The water-softening material eventually becomes charged with calcium and magnesium instead of sodium so that it is no longer effective as a softening agent. It is then treated with a solution of sodium chloride or common salt, with the result that the calcium and magnesium are replaced by sodium, so that the water-softening material is again ready for use.

A similar process takes place in soils. If, for example, a sufficient amount of sodium nitrate is applied to a soil, the sodium replaces calcium from certain solid-phase components with the formation of soluble calcium nitrate. In turn, solid-phase sodium compounds corresponding to the original calcium materials are formed. Consequently, base exchange may bring about pronounced changes in the composition of fertilizers after they are applied to the soil. Furthermore, the amount and character of the replaceable bases vary in different soils, with corresponding effects upon the ultimate composition, and possibly thereafter the action, of the same fertilizers. This problem is again referred to in the discussion of fertilizer materials.

## FERTILIZER MATERIALS AND SOIL AMENDMENTS

### GENERAL CONSIDERATIONS

As remarked earlier, the fertilizer requirements of citrus will vary greatly, owing to differences in soils and climatic conditions. Among the substances that are or have been used by citrus growers as fertilizers or soil amendments are organic materials and compounds of nitrogen, phosphorus, potassium, calcium, sulfur, and magnesium. The soil may also be deficient in boron, copper, manganese, or, most commonly, zinc. These elements, as well as others

that are necessary for plant growth in mere traces, are frequently spoken of as "minor elements." It is a rather misleading term, since the effect of the lack of any one of them upon citrus trees may by no means be of minor importance. Copper, zinc, and manganese may be applied to the soil; but it has been found that for citrus, in California, the most practical means of dealing with deficiencies in these elements is to spray the trees with dilute suspensions of compounds containing one or another of them as the need may arise. (For general recommendations elsewhere, see p. 356.) The "minor elements" are among the ones that commonly become toxic if they are present in quantities slightly greater than those required for normal growth of the trees. For example, boron is deficient in some of the soils of citrus orchards in Africa (Morris, 1938) and, on the contrary, is rather commonly found in California in amounts that are toxic.

## ORGANIC MATERIALS

The most obvious result of applying organic matter to soil is an improvement in structure: the soil becomes more friable. Another common effect, especially in irrigated areas, is the increased rapidity with which irrigation water penetrates, owing partly to the physical effect of applying the organic material and partly to the products of its decay. Organic matter has been found especially valuable to many Florida soils. Studies of approximately 100 orchards growing in the extremely sandy soils of Florida have shown (Peech, 1939) a direct relationship between the base-exchange capacity and the organic-matter content of the soil. The exchange capacity is thought to be the best single-value index to the relative potential fertility of the various soil types planted to citrus in Florida. This author (p. 25) further states: "The higher exchange capacity and consequently the greater amounts of exchangeable bases of the surface soils, as compared with the corresponding subsoils, can be attributed also to the differences in the relative amounts of organic matter. In addition to its base-exchange properties and moisture-holding capacity, the organic matter upon decomposition liberates nitrogen, calcium, magnesium, potassium, phosphorus, and other plant nutrient elements. The carbonic acid formed resulting from the decomposition of the organic matter increases the hydrolysis of the exchangeable bases and helps to bring into solution the more insoluble minerals and compounds in the soil."

Organic matter in the form in which it exists in fertilizer material is essentially a transitory constituent of the soil. In most citrus groves new supplies are constantly being added and old material is constantly being decomposed.

*Decomposition.*—The decomposition of organic material when added to soil is caused partly by enzymes, but chiefly by the activities of microörganisms in the soil which use the organic matter as a source of energy. Whenever this source of energy is available, the organisms quickly multiply and destroy it. The growth and activity of soil organisms, however, depend also upon the absorption of some of the same chemical elements that are necessary to plants. Among them is nitrogen in an available form. In decaying, the organisms may absorb nitrates from the soil if the nitrogen content of the organic matter is

too low in proportion to its carbon content. (See "Carbon:Nitrogen Ratio," below.) Some of the nitrogen is released to the soil when the process of decay slows down and the organisms die. In any given soil, the varions processes of decay proceed at varying rates until an equilibrium is reached. So long as the general conditions remain the same, the organic matter in the soil tends to remain rather constant in amount and composition.

*Carbon:nitrogen ratio.*—The results of many investigations show (Waksman, 1924; Salter, 1931) that under most farming conditions there exists a more or less constant ratio between the carbon content and the nitrogen content of the soil, usually varying from 8:1 to 12:1 regardless of the ratio of these elements in the organic material which may be added to the soil from time to time. That is, for every 8 to 12 parts of carbon there exists in the soil 1 part of nitrogen; the average ratio is about 10:1. This is a dynamic equilibrium, and changes are constantly going on that tend to balance it.

The effect of an organic fertilizer upon soil fertility is dependent in some measure upon the nature and rate of its decomposition. The decomposition is essential to the formation of soil organic matter, the liberation of the chemical elements contained in it, and the formation of nitrates from the nitrogenous part of the organic matter.

Furthermore, organic matter, in decomposing, may liberate plant foods from minerals in the soil and from relatively unavailable inorganic chemical fertilizers. The solubility of calcium, magnesium, iron, and phosphorus were measurably increased (Jensen, 1917) in the soils of the Riverside, California, district by the addition of green manure, stable manure, or their extracts. The organic matter is also an important source of available nutrient elements, aside from any effect it may have upon soil constituents.

It is well known that organic substances low in nitrogen, such as some leaves, cornstalks, and cereal straw, are not good fertilizers if used alone on an infertile soil. The application of these materials may indeed do harm during the period of their decay by depriving the growing crop of some of the nitrates stored in the soil. Experiments by Lyon, Bizzell, and Wilson (1923) illustrate this principle. Plant roots of widely varying nitrogen content were added to twenty-eight pounds of sandy soil that was low in organic-matter content. A container of soil with dried blood added was also included in the series. The amount of each material added was sufficient to contribute the same total amount of nitrogen to each respective container. Soil alone, for the control, was also included in the series.

The amounts of nitrate recovered by leachings of the soil in these respective containers are shown in table 25. The recovery of nitrate from different mixtures differed widely and was proportional to the percentage of nitrogen in the added material. The materials with narrow carbon:nitrogen ratio were most effective. The results might erroneously be taken to indicate an assimilation of nitrate from soil, under all conditions, by the soil organisms when the nitrogen in the added material was less than 1.8 per cent. That the extent and duration of this assimilation of nitrate from the soil will depend upon the initial nitrate content of the soil as well as the nitrogen content of the

added organic matter has been brought out by the studies of Crowther and Mirchandani (1931, p. 523), who concluded that "the 'slow and steady' action of nitrogenous fertilisers desired by farmers probably depends more on the previous history of the soil than on the specific properties of the fertiliser."

Loss of nitrates from citrus soils by leaching may be relatively low in irrigated orchards, as compared with that in areas of great rainfall. In citrus orchards that are heavily fertilized, especially in furrow-irrigated orchards, there may be an accumulation of from five to thirty parts per million of nitrate in the top four feet of soil. Materials with a wide carbon:nitrogen ratio may be used more effectively under such conditions than where the nitrate content of the soil is low.

TABLE 25

RELATION OF NITROGEN CONTENT OF VARIOUS PLANT ROOTS TO NITROGEN IN LEACHINGS FROM SOIL IN WHICH THEY DECOMPOSED*

| Material[a] | Nitrogen | Weight of roots added | Nitrogen in leachings |
|---|---|---|---|
| | *per cent* | *grams* | *milligrams* |
| Control | ... | ..... | 947 |
| Oat roots | 0.45 | 133.3 | 207 |
| Timothy roots | 0.62 | 96.8 | 398 |
| Maize roots | 0.79 | 75.9 | 511 |
| Clover roots | 1.71 | 35.1 | 924 |
| Dried blood | 10.71 | 5.6 | 1751 |

* Condensed from Lyon, Bizzell, and Wilson, 1923, pp. 464 and 465.
[a] The same total amount of nitrogen applied by all materials.

When organic materials with a wide carbon:nitrogen ratio are applied to a soil that is low in nitrate content, it may be desirable to apply also some concentrated, quickly available nitrogenous materials such as nitrate- or ammonia-containing fertilizers. This is especially important if the organic matter is applied in large amounts or if the application is made in the growing season for citrus trees. The use of supplementary nitrogenous concentrates is especially important if straw or strawy manure is used. Even high-grade dairy manure may cause a depression of nitrates in the soil for a few weeks immediately after its application.

Typical analyses of bulky organic materials, commonly used for fertilizers, and of cover crops are shown in table 26. To convert data in terms of organic matter of fertilizers and soils to organic carbon, multiply by 0.580; and to convert carbon to organic matter multiply by 1.724. The range of the carbon : nitrogen ratio in the fertilizer materials varies from 14 : 1 to 71 : 1, and obviously they may have to be used differently from each other if equally satisfactory results are to be obtained.

Some of the factors that influence the rate of decomposition of organic fertilizers are beyond the power of the farmer to modify. These may include, in part, soil temperature, aeration, moisture supply, and the nature of the microörganisms present. The chemical composition of the organic fertilizer, especially the proportion of carbon to nitrogen in the material, also has a

striking effect upon decomposition. The farmer may, by a choice of materials, influence this situation. Other things being equal, the materials that are relatively low in carbon and high in nitrogen decompose most rapidly.

## FARMYARD MANURE

*General effectiveness.*—Possibly the most widely used organic fertilizers in citrus culture in California, as well as in general farming elsewhere, are the various farmyard manures. Many studies have been made for the purpose of determining the relative efficiency of manure as compared with other sources

TABLE 26

TYPICAL AVERAGE ANALYSES OF BULKY ORGANIC MATERIALS

| Material | Per cent nitrogen | Per cent organic matter | Per cent phosphoric acid ($P_2O_5$) | Per cent potash ($K_2O$) | Carbon-nitrogen ratio |
|---|---|---|---|---|---|
| Dairy manure (fresh) | 0.50 | 22.60 | 0.24 | 1.00 | 26 : 1 |
| Feed-yard manure | 1.25 | 45.67 | 0.61 | 2.39 | 21 : 1 |
| Poultry manure no. 1[a] | 2.50 | 60.00 | 2.50 | 1.20 | 14 : 1 |
| Poultry manure no. 2[a] | 1.60 | 50.00 | 1.25 | 0.90 | 18 : 1 |
| Hog manure[a] | 1.60 | 52.00 | 2.10 | 1.01 | 19 : 1 |
| Sheep manure[a] | 1.60 | 50.00 | 1.50 | 1.50 | 18 : 1 |
| Alfalfa hay[a] | 2.63 | 83.79 | 0.56 | 1.85 | 19 : 1 |
| Alfalfa straw[a] | 1.50 | 82.00 | 0.30 | 1.50 | 32 : 1 |
| Lima bean straw | 1.34 | 82.80 | 0.27 | 1.25 | 36 : 1 |
| Cereal straw | 0.70 | 85.29 | 0.34 | 1.60 | 71 : 1 |
| Cotton hulls[a] | 1.20 | 80.00 | 0.50 | 4.00 | 39 : 1 |
| Vetch cover crop[b] | 3.01 | 68.70 | ... | ... | 13 : 1 |
| Mustard cover crop, mature[b] | 1.51 | 68.36 | .... | .... | 26 : 1 |
| Mustard cover crop, young[b] | 3.48 | 59.45 | ... | .... | 10 : 1 |

[a] From data of Caryl, 1940, p. 29.
[b] From data of Crowther and Mirchandani, 1931, p. 496.

of nitrogen. Some of the work has been conducted in the greenhouse and the laboratory. Annual crops have most frequently been used as indicator crops. The utilization of nitrogen in manure has varied from 13 to 58 per cent of the total applied (Heck, 1931) in some of these experiments. Usually, however, the chemical fertilizers employed for comparison with manure—especially nitrogen—have not been applied for the purpose of providing the same amount of nutrients as are contained in the applications of manure. Under the soil conditions that obtain in many areas, the fertilizing value of manure may depend on the phosphate and potash it contains as well as the nitrogen. Compared with a mixed commercial fertilizer, the nitrogen, phosphate, and potash content, respectively, of feed-yard manure will be approximately 1.25, 0.61, 2.39, plus 45 per cent organic matter. Even though manure is used in large amounts, its efficiency will be relatively low, especially when used with annual crops, probably because the nitrogen in manure is less available than the nitrogen in commercial fertilizer concentrates.

The amount of manure used in both pot and field experiments has frequently been much in excess (Lipman, Blair, and Prince, 1928) of the amount

that would ordinarily be used in general farming, or necessary for good crop production. Under these conditions the effectiveness of manure cannot fairly be compared with that of artificial fertilizers; and furthermore, the relative effectiveness of a fertilizer cannot be judged safely when applied greatly in excess of the crop needs.

Under certain field conditions, it has been pointed out (Heck, 1931) that only the ammonia or liquid-manure nitrogen is available for the first annual crop after the manure is applied to the soil. Carefully conducted laboratory trials, however, have shown (Jensen, 1931) that in well-decomposed manure, in which practically all the nitrogen is present in organic compounds, not less than one-fifth of the nitrogen has been nitrified after 300 days. Under citrus-grove conditions, soil-temperature and moisture conditions are favorable to nitrification during most of the year; and this may, in part, explain the greater efficiency of manure as a fertilizer for citrus crops in California than for annual crops elsewhere.

The nitrification, and thus in part the effectiveness, of manure and other organic materials as nitrogenous fertilizers may vary greatly with the duration of their use, with different cultural conditions, and with different crops. Often, however, where manure has been used as a fertilizer for annual crops over a long period, and thus the residual effects have been brought to bear on successivé crops, the relative effectiveness of the nitrogen has been low. In the Rothamsted experiments (Russell and Watson, 1940) with wheat the effectiveness of nitrogen from manure has been, on the average for forty-five years, 44 per cent of that from nitrate of soda, and 50 per cent of that from sulfate of ammonia. Some of this apparent ineffectiveness may have been due to a luxury supply, as the applications of the element from manure were greater than those from the inorganic sources. In comparing the direct and residual effects of manure and chemical fertilizers in Ohio (Salter and Schollenberger, 1939) in a five-crop rotation system, after forty-three years, it has been shown that chemical fertilizers were more effective but with smaller differences than in the Rothamsted experiments. As the nitrogen applied by manure exceeded that from the chemicals in both places, the comparisons are not strictly equitable. Other experiments in Ohio, conducted for twenty years (Salter and Schollenberger, 1939), in which the same amount of nitrogen was applied from both sources, showed more nearly equivalent effectiveness. In a four-crop rotation, if the twenty-year average increase for the chemical fertilizers is taken as 100, the increases from manure have been: corn, 101; oats, 77; wheat, 60; and clover, 150.

*Effect of soil reaction on fertilizer value.*—As has already been mentioned, the soil reaction, as well as the carbon:nitrogen ratio of the material used (Jensen, 1931), may cause some variation in the effectivenses of manure and other organic matter. As a general rule, an examination of the microörganisms that decompose organic matter in an acid soil shows a predominance of various fungi. In neutral and alkali soils, bacteria are the predominating organisms (Jensen, 1931). It has been shown from the substances which they decompose that fungi build up more protoplasm and retain more nitrogen than bacteria

do (Waksman, 1924). Bacteria convert more of the organic matter into carbon dioxide, water, and ammonia. In an alkaline soil a certain part of the nitrogen added to the soil (approximately 1 part of nitrogen for each 20 to 25 parts of carbon added) is nitrified only very slowly, whereas the excess above this is liberated quite readily. In an acid soil 1 part of nitrogen for each 13 to 18 parts of carbon is only very slowly nitrified, "probably on account of the greater activity of the fungi which synthesize more protoplasm and consequently store up more nitrogen than bacteria" (Jensen, 1929, p. 80). Besides the difference in the action of soil flora which probably accounts for poorer nitrification in the naturally acid soils than in those which are alkaline, there may be also be a lower supply of calcium, phosphorus, magnesium, and some of the minor elements.

In laboratory trials of 180 days (Jensen, 1929) nearly three times as much nitrate nitrogen accumulated from manure applied to and mixed with an alkaline (pH 7.42) soil as from that mixed with an acid (pH 4.74) soil under similar conditions. This probably explains why farmyard manure is more effective in a neutral or alkaline soil than in an acid soil.

*Use of manure on fruit crops.*—Apparently some crops respond more readily to manure than others. Gooseberries have been shown (Bedford and Pickering, 1919) to respond better to farmyard manure than to chemical fertilizers, applications of each being made on a comparable nutritional basis. In trials with Washington Navel oranges at Ontario, California, in an orchard planted on Hanford gravelly loam, equal production was obtained from trees fertilized with 2½ pounds of nitrogen per tree each year supplied either from manure, tankage, ammonium sulfate, or a mixed commercial fertilizer (Booth, 1930). When each of these fertilizers was combined with a winter cover crop, yields were obtained that were essentially equal within the casual error of field trials. The trials were conducted over a period of fifteen years and leave no reasonable doubt that in orange production in California, on the soil type where the trials were made, nitrogen in manure was as effective as the other sources used. It should be pointed out, however, that these results are totally contrary to the results of experiments, and general experience as well, in Florida.

In an experiment carried out over a period of twelve years at the University of California Citrus Experiment Station (Parker and Batchelor, 1942) the Washington Navel orange yields from the various plots indicated that it is not possible to use manure as a source of nitrogen quite as effectively as the commonly used concentrates. Also, nitrogen from the combination of manure and urea in equal amounts usually produced yields larger than where manure was used alone. The nitrogen was used only moderately, the total amount being the same for each plot, and always with a winter cover crop. Bean straw, alfalfa hay, and even cereal straw were as effective as manure in combination with urea, in these trials, if the carbon : nitrogen ratio of the combinations was not too wide. How generally the results may be applied, in the various citrus-growing districts of the world, is not known. There may be other places besides Florida where they most certainly do not apply.

Much of the dairy manure available to citrus growers in California contains little nitrogen in excess of a 20:1 carbon-to-nitrogen ratio (Batchelor, 1933) unless especial care has been exercised, in the accumulation of the supply, to cause the urine to be absorbed in the solid material.

*Manure combined with concentrates.*—Laboratory investigations on the nitrification of manure nitrogen (Jensen, 1931) showed that, when manure of a 21:1 carbon-to-nitrogen ratio was mixed with soil, 22 per cent of the nitrogen was nitrified after 360 days. When a combination of manure and ammonium sulfate was mixed with soil in such proportions that the applied material had a 16:1 carbon-to-nitrogen ratio, 41 per cent of the applied nitrogen—or all the nitrogen added in the ammonium sulfate and 24 per cent of the nitrogen in the manure—nitrified in the same length of time. This may explain why some casual observations and the results of a few comparable field trials (Batchelor and Parker, 1934) indicate that better citrus yields may be expected in California from the use of a combination of manure and artificial concentrates than by the use of manure alone. This probably accords with the general experience of farmers in this state, and may be considered a safer and usually more economical practice to follow than to depend upon the use of manure alone. In Florida, on the contrary, one may question the desirability of using manure at all in citrus orchards; for reasons not well understood it has been a practical failure as a source of nitrogen in that state.

Vaile (1924) reported that the use of concentrated fertilizers over a period of years, without the addition of organic matter, had often failed to give good results in California. When 60 per cent or more of the nitrogen came from bulky manures, better results were obtained than when relatively less organic matter was applied.

It is also cheaper and possibly more profitable in many districts to use only moderate amounts of manure and reinforce it with concentrated fertilizers than to depend on the use of manure entirely. In some districts alfalfa hay, alfalfa straw, cotton hulls, cereal straw, or bean straw can be used in place of manure if the supplementary applications of concentrates are carefully made, with due regard to the carbon:nitrogen ratio of the organic material used.

*Manure and straw.*—Cereal straw used alone or as a large constituent of stable manure tends to render soil nitrogen temporarily unavailable. Unless the nitrate nitrogen of the soil is already excessively high, as it may be under arid conditions, and especially with furrow irrigation, the reduction of nitrates following applications of cereal straw alone, or in manure, may persist for some time.

It should be understood, however, that the depression of nitrate accumulation in a soil after an application of low-grade manure or grain straw is temporary. Applications of these materials as a source of organic matter should also precede the semidormant period of the citrus trees rather than the active growing period. The application of grain straw in the fall of the year, if a moderate amount is used and is thoroughly incorporated into the soil at the time it is applied, may be a safe practice. Green manure or cover crops grown in the orchards are also important sources of organic matter (see chap. viii).

In summarizing the foregoing review of the effect of organic matter and manure upon the broad complex subject of soil fertility, the following is offered as a means of briefly clarifying the subject:

1. The application of organic matter improves soil tilth. Under some systems of culture it is a requisite for the maintenance of good soil condition. Under other circumstances this item may be of little or no importance.

2. Organic material with too wide a carbon:nitrogen ratio must have supplementary nitrogen if the ill effects of temporary nitrogen tie-up are to be avoided.

3. Organic materials supply appreciable amounts of phosphorus and potassium and small amounts of other elements in addition to nitrogen.

4. The base-exchange capacity, the relative potential fertility, and the organic-matter content of the soil are interdependent in the sandy soils of Florida, on which many of the citrus orchards are planted.

5. The majority of experiments, especially with annual crops, show that not so high a percentage of the nitrogen in organic materials is recoverable by the crops as in inorganic sources of nitrogen. (See table 28, p. 341, for the beneficial effect of cover crops on orange yields.)

## NITROGEN

Nitrogen is the principal growth-promoting element, and experience the world over has shown its importance in producing good citrus crops. Most trees and plants are believed to take nitrogen from the soil as nitrate, and the term "nitrification," in the comprehensive sense, signifies the conversion of other compounds of nitrogen into nitrate by soil organisms. Nitrates are readily soluble and easily moved by water in soils. Consequently, heavy rains may carry nitrates below the root zone, especially in soils of low water-holding capacity; this may be considered the usual condition prevailing in the humid regions of high rainfall.

*Accumulation of nitrates.*—Where furrow irrigation is practiced, however, it has been shown (McBeth, 1917) that nitrates tend to accumulate at or near the surface of the soil, chiefly between the furrows, during the season of little or no rainfall. Hence, in many citrus groves which are irrigated in furrows as much as 75 per cent of the nitrate nitrogen in the top three feet of soil may be above the root zone during the dry season. In most years the dry season in the citrus districts of California extends over seven or eight months; usually there is little rain of consequence from April 1 to October 21. The surface accumulation of nitrate accounts in part, perhaps, for some of the occasions when nitrogen fertilization is inefficient. It is also believed that this accumulation is the major cause of holdover effects, from one year to another, of commercial nitrogenous fertilizers (Surr, 1927). An important practical consideration is that when commercial nitrogenous fertilizers are spread broadcast in groves irrigated in furrows, after the end of the rainy season, much of the nitrogen is likely to remain above the root zone until the following rainy season begins and enough rain falls to cause a downward movement. The lateral movement of nitrates—that is, away from the furrows—during irri-

gation has the advantage, however, of largely preventing the nitrates from being carried off in the waste irrigation water.

*Nitrogenous materials.*—Among commercial nitrogenous fertilizers which are by-products are ammonium phosphate, ammonium sulfate, castor pomace, cottonseed meal, tankage, fish meal, and dried blood. There are also various natural and synthetic products containing nitrogen, such as nitrate of soda, calcium cyanamid, urea, ammonium nitrate, anhydrous ammonia, and nitrate of lime. These materials are sold as fertilizers either separately or in combination with one another. It should be kept in mind, however, that tankage, fish meal, cottonseed meal, and mixed fertilizers contain other elements of plant food besides nitrogen. As a constituent of fertilizer, nitrogen may be classified as (1) nitrate nitrogen, (2) ammonia nitrogen, (3) water-soluble organic nitrogen, and (4) water-insoluble organic nitrogen. Nitrate nitrogen is immediately available. Ammonia nitrogen has to be converted into nitrate, or, in other words, nitrified by soil organisms, before it is fully available to most trees and plants. Finally, the conversion of organic nitrogen into the nitrate form requires several steps. In general, the greater the number of steps necessary before the nitrogen becomes available, the less efficient is the fertilizer, especially for quick-growing annual crops; but this is not necessarily true for tree crops.

*Movement of nitrogen with soil moisture.*—Where it is likely that periodical heavy rains will fall upon loose open soils and thus carry the nitrates below the root zone, it is not desirable to apply all the nitrogen in the nitrate form at one time. Experience has shown that splitting the dosage under such conditions and making more than one application of a soluble fertilizer repays the extra trouble. Simultaneous applications of nitrogen in two or three forms, some of which are only slowly available, might more economically accomplish similar results.

Base exchange plays an important part here, for ammonia compounds are commonly held or fixed in the top few inches of loam or clay loam soils. After the ammonia nitrogen has been converted to nitrate, it readily moves with the soil moisture. The fixing power of the very light sandy soils, however, is so exceedingly low that a fertilizer such as sulfate of ammonia can be leached below the root zone very quickly by excessive rains or irrigation. Where there is a probability of losses by leaching, the water-insoluble organic fertilizers have an important advantage on sandy soils, and ammonia and organic sources have an advantage on the heavier soils. On the other hand, in some citrus districts with relatively little rainfall and heavy compact soils the problem is to promote the movement of the nitrogen into the root zone rather than to prevent its leaching below that zone. Applications should then be made early in the growing season.

Some growers say it is better to apply the fertilizer in the irrigation furrows than to distribute it broadcast. Care should be taken to apply it in furrow bottoms only, as the fertilizers will not be carried down unless they are actually covered by the irrigation water. Furthermore, while such fertilizers as urea and sulfate of ammonia are readily soluble in water, they are by no means

readily moved by water in soils with a high fixing power until their nitrogen has been converted into the nitrate form. Hence, when fertilizers of this type are applied in irrigation furrows, it is advisable to run the water in the same furrows during the next two irrigations. The first irrigation supplies the moisture, which is a prime requisite for nitrification, and after several weeks the second irrigation will carry part of the resulting nitrates down within the root zone of citrus trees. There should be an interval of at least two weeks between these irrigations, to allow time for nitrification. Temperature is an important factor in nitrification, and in cool weather the interval could advantageously be longer.

Besides plentiful rainfall or overhead irrigation, basin irrigation is an efficient method of carrying nitrates downward, provided they are actually covered by the water. Where basin irrigation is only occasionally practiced, much of the surface soil, which may contain most of the nitrates and certain other compounds, is often scraped into the ridges between the basins. Little nitrate may then reach the root zone. The ideal method is to make the basins first and then spread the fertilizer and irrigate.

Some citrus growers in the arid regions dissolve fertilizers in the irrigation water before applying it; there are, in fact, good productive citrus groves in California in which this method is used. This is naturally the only practical method of applying anhydrous ammonia.

The problem of using nitrogenous fertilizers effectively, without undue loss, will depend appreciably on the soil conditions and the climate. In the desert areas the problem centers around reaching the root zone with the nitrates. In the humid sections of heavy rainfall the problem of applying such fertilizers without excessive loss by leaching is of practical concern. This is especially true for the light sandy soils, where even the ammonia fertilizers may be lost by leaching. A quickly available material such as nitrate which may be taken up by the trees before excessive loss occurs, or a slowly available material such as castor pomace, may then be preferable to an ammonia fertilizer.

Some growers believe that a fairly liberal supply of available nitrogen in the spring is desirable for citrus trees in order to provide for their needs during the blooming and fruit-setting period. Further, it is probable that the young fruit grows faster on well-nourished trees and consequently is less susceptible to "June drop." The nitrogen in bulky organic materials, such as manure or bean straw, may be but slowly available, and the amount of nitrogen already available in the soil may be temporarily reduced as they decompose. Hence such materials, especially in large amounts, should preferably not be applied in the spring.

Nitrification is slow in cold soils. Where soils do not warm up rapidly in the spring, it is well at that season to apply at least some of the nitrogen in the nitrate form. In arid regions, however, on account of the usual surface accumulations of nitrates in the dry season, the root zone may possibly be well supplied with available nitrogen from previous applications carried down by rain in the spring, especially if clean cultivation has been practiced and the rains have been opportune.

Protein nitrogen is sometimes more highly valued for fertilizing than other forms of nitrogen, but, as pointed out by Lipman and associates (1928), this idea is erroneous *per se*. There may be special secondary conditions, such as a particular crop response, soil reactions, or losses from leaching, which will amply justify an exception to this general statement. Other things being equal, the nitrogen in so expensive a material as dried blood may be less efficient for some crops than the nitrogen in a cheaper nitrate form. Such materials as blood, tankage, fish meal, and cottonseed meal are not economical sources of organic matter and, as usually applied, provide at best only small amounts. The price of these materials is determined in some degree by their competitive value as stock feed and for other uses. Castor pomace is, where available, one of the most effective sources of organic nitrogen.

*Choice of materials.*—In buying a fertilizer material for the purpose of obtaining nitrogen, the cost per unit of nitrogen should be taken into account. The season of application in relation to rainfall, and thus the movement of the nitrogen into the root zone of the trees, should also be considered. The nitrate fertilizers are immediately available as soon as they reach the root zone, but are very readily moved through the soil by soil moisture and lost by leaching. The ammonia fertilizers require time in which to nitrify and are only gradually moved into the root zone in soils containing a sizable amount of colloidal material. The nitrifying process, caused by the microörganisms in the soil, proceeds with varying rapidity, depending especially upon soil temperature and soil moisture. Whereas 100 per cent of the nitrogen in the nitrate fertilizers is theoretically available for the plant growth, only a portion (from 60 to 86 per cent) is usually available from the ammonia and organic fertilizers. The loss of nitrogen where nitrates are used, under orchard conditions, will greatly exceed the loss where ammonia or, especially, water-insoluble organic materials are used, when leaching of the soil takes place. In areas of heavy rainfall or where basin irrigation is practiced, the use of some ammonia or organic nitrogen may be expected to give better results than the use of nitrates. Even the ammonia fertilizers may lose much of their value from leaching in very sandy soils. The organic materials include dried blood, fish meal, cottonseed meal, castor pomace, manure, bean straw, and alfalfa hay. Even though these organic materials are nitrified in the soil, accompanied by some loss of the nitrogen as ammonia gas and some as free nitrogen, they still are very effective nitrogenous fertilizers for citrus trees.

The rapidity with which various nitrogenous fertilizers are nitrified and the amounts (per cent) of their nitrogen which became converted to nitrate at the end of sixteen weeks, in a laboratory experiment, are shown in table 27. The soil moisture, temperature, and air conditions were kept constantly favorable for rapid nitrification. Whereas from sulfate of ammonia 86 per cent of nitrogen became available as nitrate at the end of the sixteen weeks, from cottonseed meal only 62 per cent became available. Subsequent periodical observations were made of the nitrate content of samples comparable to those for which data are presented in the table. The complete data indicate that, under the conditions which existed in this experiment, practically the maxi-

mum nitrification had taken place by the sixteenth week. Under less favorable conditions of temperature and soil moisture a longer period would be required to complete the nitrification. In spite of such laboratory trials as that just mentioned, the effectiveness of different nitrogen carriers in producing citrus crops may be closely similar under field conditions. Soil acidity, temperatures, residual effects of past treatments, effect of the fertilizer on the physical condition of the soil, and other like factors, may have a direct bearing on the problem. The conditions under which some short-term field trials in California have been conducted have indicated that the choice of nitrogen carriers there can safely depend chiefly upon the price per unit of nitrogen. Experiments

TABLE 27

PERCENTAGE OF TOTAL NITROGEN THAT BECAME AVAILABLE AS NITRATE FROM DIFFERENT FERTILIZER MATERIALS

| Material | Percentage of total nitrogen nitrified at end of the weeks specified | | |
|---|---|---|---|
| | Second week | Eighth week | Sixteenth week |
| Sulfate of ammonia | 56 | 72 | 86 |
| Dried blood | 40 | 56 | 78 |
| Urea | 56 | 60 | 78 |
| Calcium cyanamid | 3 | 64 | 74 |
| Cottonseed meal | 36 | 64 | 62 |

carried on at Ontario, California (Booth, 1930), as well as more extensive trials conducted later for a twelve-year period at Riverside (Parker and Batchelor, 1942), support this conclusion. Table 28, from the latter experiment, indicates that orange trees may use nitrogen from various sources with equal effectiveness. This is not true for all citrus-growing regions of the world. The impurities in the fertilizer materials, the effects on the soil reaction, effects on the physical condition of the soil, the leaching losses under other climatic conditions than those in California, may all be pertinent considerations which were not apparently important in either of the trials mentioned above. All the trials mentioned were conducted over too short a period of years to constitute a safe guide for concluding that the choice of nitrogen materials should depend mainly upon the cost per unit. The experiences in Florida show clearly that it is not true for that state. Local conditions vary so widely in various citrus-producing areas of the world that the advice of the local experiment stations should be sought before a citrus grower embarks upon a restricted program of fertilization over a prolonged period.

The aim here, in the main, is to discuss the principles of fertilizing rather than to make specific recommendations for all conditions. A good practice in one region may not be equally profitable in another. For example, animal manures and other bulky organic materials are cheaper in some districts than in others, and more effective as a source of nitrogen. But even where such materials are relatively expensive, there may be justification for the practice

of using bulky organic materials as a source of part of the nitrogen. The beneficial effect of the organic matter upon the soil structure may be an added advantage which will justify the practice, especially in orchards on soil types which do not readily absorb water. There, the addition of organic matter to the soil is decidedly a help in making the soil more readily permeable to irrigation water and rainfall. Where cover crops are grown in the orchard, the purchase of animal manures may not be so fully justified unless they are relatively cheap.

TABLE 28

RELATIVE ORANGE YIELDS, SHOWING EFFECTIVENESS OF VARIOUS CONCENTRATED NITROGENOUS FERTILIZERS*

(Winter cover crops grown. Nitrogen applied broadcast in the spring at the rate of one pound per tree annually)

| Treatment | 1928–1931 | 1932–1935 | 1936–1939 | 1928–1939 |
|---|---|---|---|---|
| | Mean annual yield per tree, pounds | | | |
| Nitrate of soda | 114 | 145 | 120 | 126 |
| | Relative yields[a] | | | |
| Nitrate of soda | 100 | 100 | 100 | 100 |
| Nitrate of soda and gypsum | 105 | 105 | 103 | 105 |
| Nitrate of lime | 108 | 110 | 99 | 106 |
| Sulfate of ammonia | 98 | 97 | 95 | 97 |
| Urea | 104 | 98 | 100 | 100 |
| Dried blood | 100 | 103 | 100 | 101 |
| Cottonseed meal | 94 | 101 | 94 | 97 |
| Mixed sources of nitrogen[b] | 103 | 102 | 96 | 100 |
| Cover crop only | 72 | 47 | 17 | 45 |

* From Parker and Batchelor, 1942, p. 6.

[a] Yields for the nitrate of soda treatment are assigned a value of 100, and all other yields are expressed in relation to them.

[b] Nitrate of soda, dried blood, and sulfate of ammonia supplying equal amounts of nitrogen.

In California it is a common practice among citrus growers to supply approximately half the nitrogen from bulky organic sources. Practical considerations such as prices of the fertilizer materials and their effects on citrus yields, as well as upon the soil conditions, are the controlling factors.

## PHOSPHORUS

Phosphorus, like nitrogen, is essential to plant growth. Citrus trees do not take up nearly so much phosphorus as either nitrogen or potassium, however.

*Phosphate accumulations.*—Unlike nitrates, phosphate is quite securely held by soils. Collison (1919, p. 48) says, of some experiments on rather coarse sands in Florida: "A large proportion of the phosphoric acid applied in the fertilizer is retained in the upper nine inches of soil. Practically none is leached out." At Gainesville, where some of these trials were carried on, the rainfall averaged about forty-nine inches a year throughout the period of the observations.

Studies in Florida (Bryan, 1933) have shown, especially in mature citrus groves, that in the top three feet of soil there are marked accumulations of phosphorus which have resulted from relatively liberal yearly applications of phosphoric acid, the usual procedure in fertilizing bearing groves in that state. After studying the soils from nearly one hundred citrus orchards in Florida, Peech (1939, p. 37) concluded: "The use of phosphatic fertilizers has, in some cases, definitely increased the amount of readily soluble phosphorus in the soil. Most grove soils were found to contain from 100 to 600 pounds of readily soluble phosphorus as determined by Truog's method. In a general way, the acid-soluble phosphorus content in surface soil samples was related to the age of the grove. The amount of water-solnble phosphorus was found to increase with the increasing amount of acid-soluble phosphorns in the surface layer. Although the exact nature and the availability of the accumulated phosphorus have not been established, the large amounts of water-soluble phosphorus found in some of the grove soils showing a high content of acid-solnble phosphorus would indicate that it should be readily available."

In California it has been found (Stephenson and Chapman, 1931) that applications of phosphate moved slowly into the first and second feet of soil. In groves that have been repeatedly fertilized with phosphate or manure most of the citrus soils of California show a decided increase in available phosphate (Chapman, 1934), in comparison with adjacent unfertilized areas. Areas that have been consistently fertilized with phosphate for twenty years or more may show a movement of phosphorus even into the fourth foot from the surface.

*Penetration of phosphate in soils.*—Comparisons of the relative penetration of phosphorus from bone meal, phosphates, and manure (Stephenson and Chapman, 1931) have disclosed several important results. After twenty-two annual applications to a loam soil in California there was no evidence of a penetration of water-soluble phosphate below a depth of 12 inches in plots fertilized with bone meal, as compared with penetration to depths of 24 to 36 inches in plots fertilized with superphosphate or manure. There are indications that phosphorus in manure moves readily through the soil. This may possibly be due to the improved soil structure brought about by the presence of the organic matter. On the very sandy soils of Florida, bone meal has been a satisfactory source of phosphorus, however, when used in citrus orchards.

*Phosphate from manure.*—The availability of the phosphoric acid in manure differs from that of nitrogen in being practically equal to that of mineral fertilizers (Salter and Schollenberger, 1939). In fact, studies designed (Gardner and Robertson, 1935) to compare the value of manure as a source of phosphorus with treble superphosphate indicated that manure much more effectively increased the available phosphorus.

The stability with which phosphate remains in the soil has a direct bearing on any fertilization that may be economically justified on land previously treated with either phosphate concentrates or with rather large amounts of manure. A large proportion of the citrus groves of California and Arizona are fertilized in part with dairy manure or other organic materials. Moderate applications of manure may be equivalent to 300 to 900 pounds of superphos-

phate (16 per cent $P_2O_5$) per acre. Many groves that have been so treated no doubt have available a much larger supply than exists in the virgin soil; in fact, an ample supply for many years to come. In the noncalcareous soil types, typical of the citrus areas of southern California, there is reason to believe that sources of applied phosphate from manure will remain relatively available for a long time. In calcareous soils as well as acid soils the applied phosphates may gradually revert to less available forms.

*Phosphorus in soils of arid regions.*—Even though the inherent supply of phosphorus is relatively high in the common orchard soils of the arid regions, numerous field trials have nevertheless been conducted on various soil types in California to determine the relative response of citrus crops to phosphate fertilizers. Without exception, these have shown negative results (Chapman, 1934) as indicated by fruit production; and there has been no effect on the quality of the fruit (Booth, 1930; Batchelor and Parker, 1934). Some investigators have directed attention to the fact that the phosphate fertilizers did not even improve the growth of cover crops or weeds in the experimental areas. The logical conclusion from these results must be that the soil types commonly used for citrus in California are amply supplied with phosphorus for the needs of citrus trees.

There are soil types, rarely found in the citrus areas of California, which apparently are deficient in available phosphorus, as measured by annual crops. This cannot be taken as an indication of the probable response of citrus trees, however. Experiments have shown (Crandall and Odland, 1932) that even the commonly grown vegetable crops may respond very differently to applications of phosphate and potash. If the applications of phosphate on such soils should directly benefit cover crops, then possibly the tree crops would be indirectly favored by the increased growth of organic matter. The necessity of applying superphosphate to such soils, in addition to manure or other organic materials, may be inferred if the cover crops respond to this material. Additional observations and experience will be necessary to justify such applications finally.

The indications from both pot cultures and field trials are that available phosphorus is not lacking for tree crops where cover crops and weeds make a rank growth. It may be repeated here that the soil types on which citrus is most commonly grown in the arid Southwest are not low enough in phosphorus to make its use measurably effective. It is a relatively cheap fertilizer material and should be used wherever there is a probability of its paying a return on the expenditure. The use of any fertilizer, however, which is not a profitable investment cannot be justified.

*Use of phosphate in Florida.*—The humid conditions of Florida and the use of sandy soils for citrus production have prompted, in that state, the practice of making relatively liberal applications of phosphate. It is a cheap material, locally produced, and its continued use in many old Florida orchards has, in general, been associated with profitable yields. Breazeale and Burgess (1926, p. 236) state that "plants are able to absorb phosphorus readily from solutions as dilute as one-tenth of a part per million." Consequently, a very

small amount of available phosphorus in the root zone may be sufficient, provided that amount is maintained during the growing season.

*Phosphate materials.*—Various phosphorus compounds are used as commercial fertilizers. The chief material is superphosphate, which is made by mixing together about equal weights of finely ground phosphate rock and sulfuric acid. The principal purpose of adding the acid is to render the phosphate soluble. The finished product is known as superphosphate and is commonly mentioned with a prefix to the name. For example, "16 per cent superphosphate" means that it contains 16 per cent of $P_2O_5$, or phosphoric anhydride. It does not thus occur in fertilizers, however, for it combines actively with water. Finally, some metallic elements such as calcium or sodium enter the equation. Most of the phosphorus in the superphosphate is in the form of monocalcium phosphate, which is soluble in water. Ordinary superphosphate contains a large amount of gypsum. Double superphosphate may be characterized as superphosphate without the gypsum. Treble superphosphate is essentially the same as double. Other calcium phosphates, which are insoluble in water, are present in phosphate rock and in bones.

Bone meal is sold either as steamed bone meal, which has been steamed under pressure, or as ground raw bone. The steaming removes about half the nitrogen present in raw bone, but the resulting phosphate is more readily available as a fertilizer material. The phosphoric acid of animal tankage and of fish meal is mainly from the bone content.

Ammonium phosphates are synthetic products which are relatively high in water-soluble phosphoric acid and are thus sources of both phosphorus and nitrogen.

Metaphosphate has recently been developed as a factory product by the Tennessee Valley Authority. This material contains approximately 62 per cent of available phosphoric acid.

Little phosphorus is actually removed in citrus crops. In California, for example, a crop of oranges considerably above average is 300 packed boxes per acre, or approximately 21,600 pounds net weight. This amount of fruit would remove only about 11.88 pounds of phosphate per acre.

## POTASSIUM

Like nitrogen and phosphorus, potassium is absolutely essential to plant growth. When applied to soils, the potassium in potash compounds is apt to be firmly fixed by base exchange: the potassium changes place with other bases, such as calcium, and unites with soil components previously combined with calcium, giving rise to more or less complex silicates containing potassium. When sulfate of potash is applied to a soil the potassium may replace calcium, with the formation of calcium sulfate; hence, white soil-surface coatings of gypsum often follow applications of potassium sulfate.

*Potassium held by the soil.*—The potassium in soils is held mainly by the clay or clayey materials, and, even in a relatively humid country like England, clay soils commonly make little or no response to applications of potash compounds, in spite of being subjected to heavy rainfall.

On the other hand, the clay content and the potassium content of the citrus-orchard soils of Florida are low, and fertilizers are applied primarily as salts of potassium. After studying these orchard soils in Florida, Peech (1939, p. 18) concluded: "If comparison is made of the small amounts of potassium found in acid sandy soils low in exchange capacity, with an average annual application of potash commonly used, it would seem that the loss of potassium through leaching in such soils has been much greater than is usually assumed."

TABLE 29

WATER-SOLUBLE POTASH ($K_2O$) IN THE SOIL OF PLOTS FERTILIZED WITH DIFFERENT MATERIALS*

(Same fertilizer program for each plot of orange trees for seventeen years)

| Sampling depth | Water-soluble $K_2O$ in dry soil[a] receiving different treatments | | |
|---|---|---|---|
| | Fertilized with sodium nitrate, dried blood, and sulfate of potash[b] | Fertilized with manure[c] | Unfertilized |
| *inches* | *p.p.m.* | *p.p.m.* | *p.p.m.* |
| 0–6 | 85 | 73 | 18 |
| 6–12 | 43 | 52 | 20 |
| 12–24 | 32 | 21 | 13 |
| 24–36 | 12 | 17 | 8 |
| 36–48 | 14 | 11 | 13 |
| 48–60 | 11 | 13 | 10 |
| 60–72 | 9 | 7 | 8 |

* From unpublished data on file at the University of California Citrus Experiment Station, Riverside, California.

[a] Average of two plots each.

[b] Sulfate of potash applied annually at the rate of 292 pounds per acre.

[c] Barnyard manure applied annually at the rate of 1,090 cubic feet per acre.

There has been a notable increase in the content of water-soluble potash in the top two feet of soil of the fertilizer plots maintained by the University of California Citrus Experiment Station. Moderate amounts of sulfate of potash and of manure have been applied to this Ramona loam every year for seventeen years. The increase is especially significant at a depth of from 6 to 24 inches. Within this zone the citrus-tree roots are probably more densely distributed than in any other part of the soil mass. Table 29 shows comparisons between the water-soluble potash of (1) the plots receiving sulfate of potash, (2) those receiving dairy manure, and (3) those receiving no fertilizer. The averages are based upon the careful sampling of two plots in each treatment. It is evident from these trials that a moderate application of dairy manure at the rate of 1,090 cubic feet per acre annually for seventeen years increased the water-soluble potash of the plots to essentially the same amount as the increase which resulted from the application of sulfate of potash. The small difference recorded is within the casual error of soil sampling. It is interesting to note from this table that, although the potash has been gradually carried well within the zone of densest citrus-root development, it apparently has not been lost

by leaching below the limits of the root system. There is much more clay in this soil than in the Florida soil with which Peech (1939) worked, a fact which offers the most probable explanation of the difference in the results. Much of the surplus of potassium applied in fertilizers will probably remain in soils for many years, especially in soils with a rather large clay content.

*Potash in manure.*—Oftentimes, citrus orchards receive a great deal of potash from materials that are purchased and applied because they contain other constituents. High-grade feed-yard manure will likely contain more than 2 per cent potash ($K_2O$). The manure may be used primarily as a source of nitrogen and organic matter; nevertheless, relatively large applications of available potash (Batchelor, 1933) are made to the soil in this material. For example, 5 to 10 tons of manure per acre are frequently applied in many groves in Arizona and California. This might, therefore, apply the equivalent of 400 to 800 pounds of sulfate of potash (49 per cent $K_2O$) per acre.

The potash content of other commonly used bulky organic fertilizers may also make noteworthy additions to the potash content of an orchard soil. Analyses of some of the most commonly used materials are shown in table 26. It is improbable that potash salts need be applied to citrus groves to supplement manure, or other bulky organic materials such as alfalfa hay, bean straw, or cereal straw.

*Experiments using potash.*—Numerous experiments made during many years have failed to show any benefit to citrus trees in California from applications of potash in commercial fertilizers. The experiments (Parker and Batchelor, 1942) have been carried out over a series of years on the various soil types of the State on which citrus orchards are most commonly grown. When results such as they show are obtained by the use of potash concentrates without manure, it is clearly less probable that potash will be effective in commercial orchards which currently are, or heretofore have been, fertilized with manure.

The usual complete lack of any measurable effect from the use of potassium in citrus groves in the arid Southwest is believed due to the high potash content of the original soils.[1] As shown in table 29, the check plots on which citrus trees have been growing for seventeen years without fertilization still show a relatively high content of water-soluble potash.

In Florida, manure has not generally proved satisfactory as a fertilizer for citrus orchards. The use of some commercial potash fertilizer is a common practice there. The application in proportion to nitrogen and phosphate is relatively large in many of the successful citrus orchards.

*Potash materials.*—Potash salts for fertilizer purposes were formerly supplied primarily from deposits in Germany and France, and secondarily from deposits in the United States. Since 1932, domestic production has increased rapidly, and by 1938 the United States production was 270,000 short tons of $K_2O$. This amounted to approximately 60 per cent of the total consumption for the country. By 1942, the United States production amounted to practi-

[1] Some of the irrigation water used in California contains water-soluble potassium to the extent of 5 to 7 parts per million.

cally the total use in this country of 539,000 tons of actual potash ($K_2O$).[1] American deposits, however, were severely exploited in the war years.

The two compounds most commonly used are muriate of potash (potassium chloride) and potassium sulfate. The fertilizer grade of muriate of potash should contain not less than the equivalent of 48 per cent potash ($K_2O$). The two grades most frequently merchandised contain the equivalent of 50.5 per cent or 60 per cent $K_2O$. The fertilizer grade of potassium sulfate contains 48.7 per cent $K_2O$. Sulfate of potash-magnesia is extensively used in Florida as a source of both potash and magnesium. It contains not less than 25 per cent potash ($K_2O$) and not less than 25 per cent sulfate of magnesia, and not more than 2.5 per cent chlorine. Another compound less commonly used is potassium nitrate, 46.6 per cent $K_2O$ plus 13.9 per cent N. There is also a product called nitrate of soda potash which is approximately a mixture of 75 per cent nitrate of soda and 25 per cent nitrate of potash. This is more commonly used in producing mixed fertilizers or as a top dressing.

### CALCIUM

Another element essential for plant growth is calcium, and citrus trees contain relatively large amounts of it; in fact, about a third of the ash of citrus leaves is calcium. It is possible, however, that this amount of calcium is in excess of the actual requirements. Lime is calcium oxide, and all lime compounds are necessarily compounds of calcium. For many years limestone, marl, and various forms of "agricultural" lime have been used on acid soils to neutralize the acidity and thus make it possible for satisfactory field crops to be grown. It so happens that citrus trees grow well on somewhat acid soils, such as those in Florida and elsewhere.

*Effect of soil acidity on citrus trees.*—Extended studies on this subject (Fudge, 1930) showed that the best tree conditions were to be found in the groves along the "ridge" in central Florida where the pH is below 6.0. On the east coast of Florida, however, where "the content of organic matter is much greater in this soil than in the ridge soils," good tree conditions were found where the pH varied from 5.5 to 7.7 in the surface foot of soil. It has been found, subsequent to this study, that the application of nutritional sprays containing both zinc and manganese will make it possible for citrus trees in Florida to thrive in soils with a pH as high as 7.0 or 8.0.

The acidity of the soil may have an indirect effect on the loss of essential elements such as magnesium (see "Magnesium," p. 350). Even though citrus trees may have a wide range of adaptation to varying degrees of soil acidity, on certain soil types secondary effects may occur which may profitably be corrected by changing the pH of the soil.

*Effect of liming soils on zinc deficiency.*—Liberal applications of ground limestone in Florida (Floyd, 1917) have been followed, in some orchards, by pronounced and persistent injury to the citrus trees by mottle-leaf or "frenching." The small supplies of zinc in the soil were rendered unavailable because of the reaction of the lime (see "Zinc," p. 356). Modifications of the soil reac-

[1] Data prepared by the National Fertilizer Association.

tion by applications of lime should be made with extreme caution and only when all the ramifications of the problem are understood.

Of central Florida orchards, Fudge (1930, p. 6) says, "it is quite evident that the groves which have received sufficient lime to bring the hydrogen-ion concentration to pH 6.0 and higher have been seriously injured; not merely by lessening the fruit production but also in a great many cases by causing the death of the trees.... A point of interest in this connection is the fact that even after ten years time the ill effects of lime are still being observed." It should be recalled, however, that these observations were made before the use of nutritional sprays containing zinc and manganese were known to be of value.

Where a soil is so acid that a good cover crop cannot be grown, a moderate application of limestone may be of indirect benefit to citrus trees. The acidity of soils depends in large measure upon the amount of rainfall, with consequent leaching out of calcium compounds. Corroborative evidence is the fact that most river waters contain more calcium than any other single base; in some, however, it is exceeded by sodium.

*Calcium in soils of arid regions.*—The soils of arid regions, owing to the persistent lack of leaching, are commonly much richer in calcium than those of humid regions. Where irrigation is practiced, moreover, appreciable amounts of calcium are frequently present in the irrigation waters. Few citrus orchards in California are planted on naturally acid soils, and these are only mildly acid; most of the orchards are on neutral or slightly alkaline soils.

In the arid Southwest, chlorosis or yellowing of the leaves and a general poor condition of citrus trees and of other fruit trees are sometimes associated with large amounts of calcium carbonate in the soil and subsoil. The term "lime-induced chlorosis" is now in general use to describe this subnormal condition of trees. But large amounts of calcium carbonate within the root zone of citrus trees do not always cause "lime-induced chlorosis." In Florida, where some of the soils contain large amounts of lime but are also well drained and are subjected to heavy rainfall, the chlorosis is not marked.

In some Florida orchards, relatively thin layers of acid soil overlie subsoils with a high calcium carbonate content, and the tree roots are especially well developed in the surface soil. In Arizona, where good subdrainage will permit the use of large applications of irrigation water by the basin system, much of the trouble is apparently avoided. Under both of these circumstances, the slowly soluble calcium is continuously being leached away.

That lime is present in many California soils, in forms readily acted upon, is proved by the white coatings of calcium sulfate following applications of sulfates, such as sulfate of ammonia and sulfate of potash, even in soils that are practically free from calcium carbonate. These are examples of base exchange. Soils low in calcium carbonate may nevertheless contain calcium in readily replaceable forms, combined with silica and other compounds. The conversion of the calcium into gypsum causes the calcium to be more soluble in water and thereby more readily available to plants. Hence it is possible that applications of fertilizer may sometimes be indirectly as well as directly bene-

ficial. There is as yet no definite evidence to show that the application of lime as a nutrient has been of any direct benefit to citrus trees when they are grown in soil types in the arid regions of the United States. The calcium requirements of the trees, beyond the supply that is commonly available in the various soils prevailing in these citrus-growing areas, seem generally to be insignificant. The use of gypsum has improved the physical condition of the soil, and especially the permeability, where irrigation waters high in sodium content are used. The use of gypsum together with the persistent use of sodium nitrate fertilizer has also been advised, to prevent adverse physical effects on the soil caused by the sodium.

*Use of lime in humid regions.*—In Florida, on the sandy soils, lime has been used for the purpose of adjusting the pH of the soil to a more favorable degree of acidity in order to conserve the magnesium, which would otherwise be lost by leaching. Applications of lime for this purpose should be made with a full knowledge of the initial condition of the soil and careful calculations of the amount necessary to make suitable corrections. Excessive applications may become exceedingly harmful. It is much safer to use dolomite.

*Calcium materials.*—Limestone and marl are mainly calcium carbonate. Dolomite is a double carbonate of lime and magnesia. Gypsum is calcium sulfate. Dolomite is commonly used in correcting excessive soil acidity and is especially valuable where signs of magnesium deficiency are evident. Dolomite is not water-soluble, but it has a neutralizing effect on acid soil comparable to that of ordinary limestone (Bear, 1942), and the magnesium content may become slowly available to the trees in the future.

## SULFUR

When sulfur is applied to soils, it is oxidized by certain soil organisms into sulfuric acid, which in turn unites with the bases present to form sulfates. The organisms that oxidize sulfur are present in many soils (Haynes, 1928), including some that are strongly alkaline and unproductive; consequently, nothing is generally gained by using inoculated sulfur. After sulfur has been applied and mixed with the damp soil, white coatings of gypsum usually appear on the soil surface.

*Soil reaction to sulfur applications.*—The oxidized sulfur in acid soils increases the acidity and in alkaline soils reduces the alkalinity. In some soils the addition of sulfur increases the amount of potassium soluble in water, although this effect seems to depend on the particular soil.

Heavy applications of sulfur (Powers, 1927, p. 165) "resulted in increased soil acidity, which caused an increase in phosphate and iron content of the soil solution up to a certain point, after which bases dissolved or replaced tended to precipitate these two ions from the soil solution."

The theory that lime, gypsum, and sulfur, when applied to soils, liberate phosphorus and potassium cannot be accepted as generally demonstrable. Often there may be no such effect, and at times applications of these materials may decrease the water-soluble phosphorus and potassium.

The effect of sulfur upon nitrification should be mentioned here. Although a

little sulfur stimulates nitrification, larger applications may not only depress it, but may inhibit both nitrification and nitrogen fixation.

*Use of sulfur in orchards.*—Aside from its usefulness in correcting black alkali, it is questionable that sulfur is ordinarily of practical value in citrus orchards. Several trials in California showed negative results even where as much as forty pounds of sulfur had been applied for each tree. Sulfate of ammonia, sulfate of potash, and ordinary superphosphate all contain sulfur. In some regions lime-sulfur sprays and sulfur dusts are used annually for the control of thrips, and as a result of these practices a little sulfur reaches the soil. It should be mentioned that many of the irrigation waters, both from wells and mountain streams, contain sizable amounts of sulfur. The purchase and application of sulfur to orchards irrigated with such water might not only be a waste of money, but might also be positively harmful to the orchard.

*Sulfur in organic materials.*—Sulfur is also added when organic materials are applied as fertilizers. For example, it has been found in Wisconsin (Hart and Peterson, 1911) that where farm manure has been applied in regular and fairly liberal quantities the sulfur content of the soil has been maintained and even increased. Analyses of alfalfa hay have shown from 0.118 to 0.558 per cent sulfur; and of bean and cereal straws, from 0.106 to 0.218 per cent sulfur (Hart and Peterson, 1911; Reimer and Tartar, 1919; Hall, 1922).

*Sulfur in rain water.*—Sulfur is also contributed by the rainfall. At Rothamsted, England, over a period of seven years, the average annual quantity in the rain water amounted to almost 7 pounds of sulfur per acre (Hall, 1905). According to Ames and Boltz (1916), Kossovich found that the amount of sulfur contributed by rain varied from 9 pounds per acre annually in the country to 72 pounds per acre near towns and industrial works. Determinations in several localities indicate, according to these authors, that 6 to 7 pounds of sulfur per acre may be regarded as the average annual quantity brought down by rain in the United States. Such contributions from rain are relatively small, to be sure, but they are continuous.

## MAGNESIUM

Magnesium is among the essential elements for plant food that are sometimes applied as fertilizers. It is a constituent of chlorophyll, the green coloring matter of plants. Magnesium deficiency in the soils, especially the sandy sorts, of the Atlantic seaboard of the United States is a common occurrence. Annual plants differ (Sommer and Baxter, 1941) greatly in their tolerance to it. Tobacco, peanuts, and Crotalaria are among the annual plants that improve markedly as a result of magnesium fertilization. Crotalaria is an important cover-crop plant in the southeast, especially in Florida citrus orchards.

For nearly all the Florida soil types on which citrus crops are grown, fertilization with magnesium is a practical problem. The deficiency of this element has gradually become more general as fertilizers have been used which are freer from impurities, some of which were magnesium compounds.

*Symptoms of magnesium deficiency.*—For some time before being definitely ascribed to lack of magnesium the symptoms of magnesium deficiency in citrus

Fig. 122. Symptoms of magnesium deficiency on grapefruit leaves. (After Camp and Fudge, 1939. Courtesy of the Florida Agricultural Experiment Station and the National Fertilizer Association.)

Fig. 123. Symptoms of zinc deficiency on orange leaves and twigs. (After Camp and Fudge, 1939. Courtesy of the Florida Agricultural Experiment Station and the National Fertilizer Association.)

Fig. 124. Symptoms of copper deficiency on an orange twig. (After Camp and Fudge, 1939. Courtesy of the Florida Agricultural Experiment Station and the National Fertilizer Association.)

Fig. 125. Symptoms of copper deficiency on an orange. (After Camp and Fudge, 1939. Courtesy of the Florida Agricultural Experiment Station and the National Fertilizer Association.)

trees were recognized only as a condition of malnutrition. The symptoms were locally known as "bronzing." Irregular yellow blotches start along the midrib of leaves, especially those which are near the fruit, and eventually coalesce to form an irregular yellow band on each side of the midrib. Typical grapefruit foliage affected with magnesium deficiency is shown in figure 122. It has been shown that the symptoms of magnesium deficiency (Fudge, 1939) are associated primarily with the translocation of magnesium from the older leaves to the developing fruit and also to the younger leaves. When a large part of the leaf has turned color it may drop off. Magnesium deficiency accentuates damage from cold weather. Severely affected trees may become completely defoliated in early winter, the rate of defoliation being accentuated by cold weather. As a result, such trees bear fruit only in alternate years. The fruit of seedy varieties of both oranges and grapefruit normally contain more magnesium than those which are nearly or quite seedless; a relatively large share of the magnesium is in the seed itself. Evidently the magnesium requirements of the fruit and seeds create a deficiency in the adjacent foliage. Here and there over the tree, clusters of leaves become more bronze in color than other parts of the foliage, as a result of their proximity to the fruit. Though definite fruit symptoms characteristic of this condition have not been described, the lack of a normal intake of magnesium causes a reduction in the total yield, the size, and especially the quality (see below). The fruit has a tendency to be weak and to break down in storage, has a coarser exterior appearance, and is less fully colored externally and internally.

*Magnesium deficiency and resistance to cold.*—The effect of soil fertility upon resistance of both citrus trees and fruit to injury from cold has been observed in Florida (Lawless and Camp, 1940). In orchards fertilized so as to meet fully their nutritional requirements, trees and fruits were injured much less than in orchards that were deficient in one or more of the nutritional elements. Injury resulted when magnesium was deficient (Lawless, 1941) even though the trees were well supplied with all other essential elements. Recovery and return to normal production were especially slow in trees affected with magnesium deficiency.

*Magnesium and fruit quality.*—Experiments conducted in Florida (Cowart and Stearns, 1941) have shown that the composition of oranges has been materially affected by deficiencies of copper, zinc, manganese, and magnesium. This is especially true of magnesium deficiency; and applications of compounds containing magnesium have materially increased the quality of the fruit, as is evidenced by increase in acid, total solids, sugars, and vitamin-C content. The internal quality of grapefruit has also been improved by applications of magnesium as a tree fertilizer (Cowart, 1942) in Florida. The improved fruit had a better flavor, a larger total of soluble solids, more sugar, and a higher vitamin-C content than fruit from trees which were not fertilized with magnesium and which showed symptoms of magnesium deficiency. It is not evident, however, that any of the minor elements will improve fruit quality in general, unless specific symptoms are apparent and are corrected by the use of those elements.

*Magnesium needs in various citrus areas.*—Magnesium deficiency is not a serious problem of most of the citrus-growing areas in California since the soils are quite different from those of Florida. The impurities in the irrigation waters of California, Arizona, and Texas usually include appreciable amounts of magnesium. It seems improbable, therefore, that magnesium will be required as a fertilizer material in these three states.

Most of the light sandy soils of Florida, on the other hand, are, under normal conditions, deficient in magnesium and in manganese, copper, and zinc (Peech, 1939). The deficiencies are further aggravated by excessive leaching losses owing to heavy rainfall and by the use of acid-forming fertilizers. As a result, magnesium deficiency is general in Florida orchards on sandy soils which have a degree of acidity below pH 5.0, or in less acid soils which have an especially low magnesium level. The treatment generally practiced is to apply dolomitic limestone to increase the alkalinity of the soil and provide slowly available magnesium—usually enough to maintain the pH of the soil between 5.5 and 6.0. Dolomite may be added as a filler in mixed fertilizers. It is usually desirable also to add some soluble form such as magnesium sulfate. This may be included in the mixed fertilizers and thus save special applications. Magnesium compounds in solution applied as a spray are not effective; the citrus-tree requirements are relatively large as compared with the amount that can be absorbed by the foliage.

## MINOR ELEMENTS ESSENTIAL FOR PLANT DEVELOPMENT

For normal plant development, elements other than those discussed above are essential in small quantities only (McMurtrey and Robinson, 1938). Included in the group are manganese, boron, copper, zinc, and molybdenum (Hoagland, 1941). They are usually classified as "minor," trace, or rare elements in the role of plant nutrition. None of these terms is entirely satisfactory, as they imply that the elements are relatively unimportant or that their presence in crops and soils is infrequent. Both implications are essentially wrong.

There is only a very small margin of safety between the small amounts of these elements that are needed in the soil or cultures for plant growth and the relatively small amount that is sufficient to cause a depressed growth rate or even toxic symptoms. A detailed consideration of all these minor elements will not be given. Only those employed in the fertilization of some citrus orchards, or used in nutritional sprays, will be discussed.

The deficiency of boron in citrus-growing areas is exceedingly rare, although it has been reported (Morris, 1937; Morris, 1938) from Africa. On the contrary, boron frequently exists in toxic amounts in the citrus orchards of California. Commonly, the excess is an impurity in irrigation water. (For further consideration of this subject see Vol. 1, chap. vii, pp. 748–750.)

### ZINC

*Extent of zinc deficiency.*—Although insufficiency of zinc may occasionally be a problem with annual field crops, it is not commonly so, nor is it of eco-

nomic importance with cotton or vegetable crops in most of the production areas in North America. In some of the soils of Florida, deficiency of zinc for normal growth of corn and other field crops (Allison, Bryan, and Hunter, 1927; Barnette, 1935; Barnette, Camp, Warner, and Gall, 1936) is an exception to this general condition in the rest of the country. Zinc deficiency has been manifested as a condition of malnutrition in deciduous fruit orchards in many parts of the world.

This condition of malnutrition has been called "rosette" of pecan and apple trees, mottle-leaf or "frenching" of citrus trees, "yellows" of walnuts, and "little-leaf" of grapevines, stone fruits, and other trees. Plantings of some of the above-mentioned tree crops in closely adjacent rows produced evidence (Haas, Batchelor, and Thomas, 1928) that all these diseases were due to a similar cause and were primarily a soil problem.

The possible need of zinc as a nutritional requirement of tung trees, pecans, and oranges in Florida, and with peaches, apples, plums, walnuts, and oranges in California, and pecans in Arizona and other areas, was investigated by several research workers. Several investigators concurrently reported distinctly beneficial results from zinc (Alben, Cole, and Lewis, 1932; Chandler, Hoagland, and Hibbard, 1932 and 1933; Mowry, 1933; Finch, 1933; Johnston, 1933) upon the growth of the various species of trees under observation. The growth of the citrus trees was greatly stimulated and the mottle-leaf or "frenching" was cured by the use of zinc. Compounds of zinc were used as a spray, as soil applications, and by injections into the trees by means of holes bored in the trunks. Subsequently, more spray trials and soil applications were carried on by several investigators in both California and Florida (Camp, 1934; Mowry and Camp, 1934; Parker, 1934), and by 1935 the use of zinc sprays for the cure of mottle-leaf had become widespread in citrus-growing areas.

Zinc is commonly lacking in an available form in the soils of many of the citrus-producing areas of the world. The use of zinc is probably more important in most citrus areas than the use of any of the elements heretofore discussed, with the exception of nitrogen.

*Symptoms of zinc deficiency.*—The symptoms of mottle-leaf indicating zinc deficiency are readily distinguishable on mature citrus leaves. The normal green color of the leaves changes to yellowish green between the lateral veins, in contrast to the dark green color along the midrib and adjacent to the lateral veins. In extreme attacks the yellowish green coloration will become pale yellow. The leaves are narrow and subnormal in size, their growth is bunchy, and they tend to stand erect. The last cycle of growth in the autumn is likely to be more severely affected than the preceding cycles of the same season. Typical symptoms of zinc deficiency on orange leaves and twigs are shown in figure 123.

As the symptoms of zinc deficiency increase in intensity, the twigs and small branches die prematurely so that a tree thus affected has a noticeable amount of dead wood in it, as is shown in figure 126. The yields of affected orange and grapefruit trees are subnormal, and the fruit is smaller, thicker-


Fig. 126. Mature lemon tree showing general zinc-deficiency symptoms, with large amount of dead wood throughout the tree. (Photographed by E. R. Parker. Courtesy of the California Agricultural Experiment Station.)

skinned, and of poor quality; these differences are shown in figure 127, which pictures fruit grown in California. In Florida, internal fruit quality is affected as in California, but the exterior appearance is characterized by especially small, light-colored oranges with a smooth, thin skin.

*Treatment of zinc deficiency.*—Applications of zinc to the soil may soon become ineffective as fertilizer, owing to the formation of insoluble compounds. This is especially true in California and Texas, where the soils have a great deal more clay than the Florida soils. A means of avoiding the change of zinc

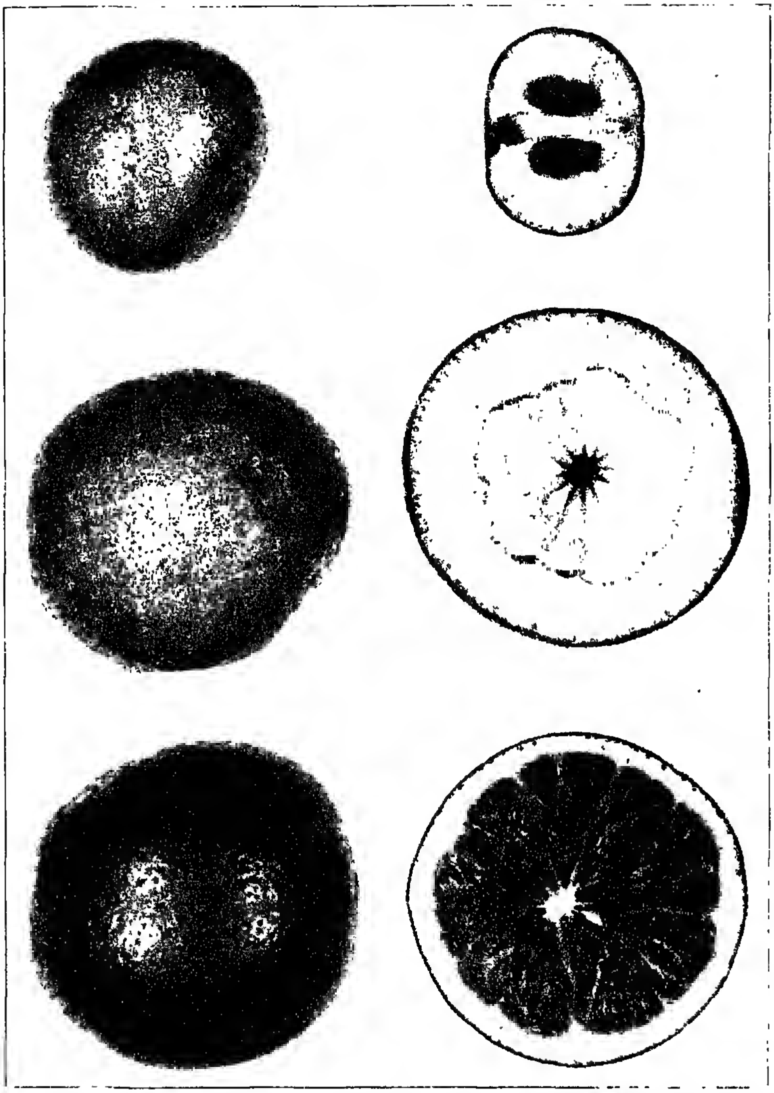

Fig. 127. Typical abnormal grapefruit produced on tree affected with zinc deficiency. The two fruits at the bottom are from trees that were sprayed with a mixture of zinc sulfate and hydrated lime at blooming time. The other fruits are from comparable untreated trees. The two fruits at the top were produced on branches exhibiting extreme symptoms. (After Parker, 1937. Courtesy of the California Agricultural Experiment Station.)

to an unavailable state is to concentrate the applications within small areas. Some trees affected with mottle-leaf have been cured in this way, but in California many have been severely injured. In Florida, some excellent recoveries

have been made by mottled trees after small applications of zinc sulfate to the soil (Camp, 1934). The method most commonly used to correct zinc deficiency is to spray the trees with a dilute suspension of some zinc compound, as the minute amounts absorbed by the foliage suffice to counteract the deficiency. Zinc sulfate neutralized with hydrated lime or lime sulfur is commonly used in Florida; zinc sulfate with lime or soda ash, or a zinc oxide, in California and other areas. Concentrations of 2½ pounds of zinc sulfate and 1½ pounds of soda ash to 100 gallons of water have been satisfactory for spraying moderately affected trees. A light mist spray over the outside foliage is all that is necessary. This may be applied rapidly and economically with a boom spray attachment such as is used in spraying for citrus thrips. Trees sprayed every two or three years usually absorb enough zinc to keep them practically free from mottle-leaf, in California. In orchards normally subject to mottle-leaf it is not advisable to wait until symptoms reappear before repeating the spraying. Under such conditions, annual spraying should be part of the fertilizer program. In Florida, it has been found advisable to apply an annual nutritional zinc spray.

### COPPER

Most agricultural soils probably contain small amounts of copper, so far as may be judged from the few studies (Manns and Russell, 1935; Peech, 1939; Peech, 1941; Sedletsky and Ivanov, 1941; Vinogradov, 1940) that have been made.

*Effect of copper on plants.*—It is certain that annual plants have been benefited by applications of copper to the soil. The applications have cured some plants with definite symptoms of malformation and have greatly increased the yields of apparently healthy plants. Benefits have been especially noteworthy where the crops were growing on sandy soils, muck soils, and so-called heath and moorland soils. Certain counties in Florida produce pasture grass so markedly deficient in both iron and copper that cattle feeding on it do not mature normally (Becker, Neal, and Shealy, 1931).

The growth symptoms of citrus trees indicating copper deficiency have been recognized in most of the countries where citrus is grown. The abnormal condition was called by various names before its relationship to copper deficiency was known; most commonly, "dieback" or "exanthema." The trouble was recognized as early as 1875 in Florida, and successful treatments with copper sprays were reported (Floyd, 1914) several decades later. The success of soil treatments (Grossenbacher, 1916) with copper sulfate soon followed. Research on several minor elements by various investigators during the past decade has added appreciably to our understanding of copper deficiency.

*Symptoms of copper deficiency.*—Trees affected by copper deficiency may produce vigorous growth of succulent, angular twigs that are too weak to stand in a normal, erect position. Sagging at the tips gives them an S-shaped appearance. Their terminal growth dies prematurely, and then the lower lateral buds send out short twigs which in turn are short-lived. The final result is an abnormal number of short, dead twigs bunched irregularly over the periphery of the tree, as is shown in figure 128. This dense bushy growth

produced by the development of multiple buds may be accompanied by gum pockets between the bark and the wood, at or near the leaf node. The effect of copper deficiency on a single orange twig is shown in figure 124, above.

Fig. 128. Young orange tree affected with acute copper deficiency. (After Camp and Fudge, 1939. Courtesy of the Florida Agricultural Experiment Station.)

Some of the fruit of affected trees is usually marked irregularly with reddish brown blotches that finally turn dark brown or nearly black on mature fruit, as shown in figure 125, above. Such fruits are of inferior quality because they are insipid and have a less than normal amount of juice. In fruits acutely affected, gum pockets are formed at the center in the angles of the segments, and in the rind. Splitting of the fruit is also a common char-

acteristic. In Florida it has been observed that fruit and foliage of trees affected with both copper and zinc deficiencies were more susceptible than normal trees to injury from cold (Lawless, 1941).

*Cause of copper deficiency.*—Copper deficiency has been studied more intensively in Florida (Camp and Fudge, 1939) than in any other citrus-growing region of this country. It is believed to be associated with acid and sandy soils in which the copper content is less than normal as a result of losses from leaching. Factors that accentuate such leaching losses are low pH and lack of cover crop during the rainy season. In Florida, the deficiency has commonly been associated with the use of large applications of ammonia or other nitrogenous fertilizers; and for this reason the typical symptoms, on the fruit especially, have been termed "ammoniated fruit." In California, the connection between copper deficiency and the use of any particular fertilizer has not been apparent.

There is some evidence that the formation of insoluble copper compounds in the light, acid soils of Florida (Peech, 1941) may be the cause of copper deficiency. The indiscriminate use of lime has been a factor in rendering unavailable both copper and zinc. Where the use of lime has been excessive, citrus trees respond to *moderate* soil applications of copper sulfate. More recent studies (Jamison, 1942) have shown that much of the copper is retained in slowly soluble or slowly replaceable forms, and apparently a small continuous supply in the soil may be more important than the amount of copper that is easily replaceable. An ordinary soil application of copper sulfate would no doubt be extremely harmful to citrus trees, were it not for its fixation by the soil.

*Treatment of copper deficiency.*—Trees growing in the sandier soils of Florida have been cured by soil applications amounting to as little as ¼ pound to 2 pounds of copper sulfate per tree (Camp and Fudge, 1939). The application of sprays of bordeaux mixture[1] may occasionally be a safer and more practical means of curing the trouble. This latter method is the only safe and practical one in common use in California. In this state there are many lemon and orange orchards in which the lower branches of the trees are periodically sprayed with bordeaux mixture to prevent brown rot of the fruit. This may be one of the reasons why copper deficiency is not a serious problem in California. Trees sprayed with copper solutions or those which have been treated with copper in the soil are liable to severe injury by subsequent fumigation with hydrocyanic acid gas, which is the common means of controlling several scale insects in California. There should be an interval of several months between a spraying with copper solutions and a fumigation. Obviously, copper should not be included in a mixed fertilizer sold for use in California, but should be used in the most effective manner practicable if deficiency symptoms are evident, and with full consideration of plans for orchard fumigation.

In Florida, where fumigation is not used as a means of insect control, it is becoming a common practice to apply mixed fertilizers containing water-

[1] Only moderate-strength bordeaux is necessary, such as 6–4–100.

soluble copper. Where melanose or scab control is desirable, a copper spray for nutritional purposes may profitably be applied in combination with zinc.

MANGANESE

"The amount of manganese found in soils is exceedingly variable, the range in surface soils of the United States being from less than 0.001 per cent to 1.27 per cent, while some tropical soils contain as much as 15 per cent" (Jacks and Scherbatoff, 1940).

There are many references in various parts of the world to manganese-deficiency symptoms appearing on annual and tree crops. Although manganese is an essential element for plant growth, it may occur in some soils in toxic amounts, like boron and copper. There is only a small margin between a deficiency and an excess of these elements. Excess of manganese has been reported in some of the citrus orchards of South Africa (Van der Merwe and Andersen, 1937).

*Symptoms of manganese deficiency.*—The symptoms of manganese deficiency of citrus trees do not have a common name, although the terms "marl frenching" and "marl chlorosis" have been used (Camp and Fudge, 1939) in Florida. These, however, generally described a condition of combined manganese and zinc deficiency which could not be cured unless both elements were applied. Manganese deficiency not in association with zinc deficiency has been observed in California (Parker, Southwick, and Chapman, 1940), and affected trees have responded to applications of manganese alone. Young leaves show a network of dark green veins on lighter green background. Various degrees of the deficiency symptoms on orange leaves are shown in figure 129. A large number of the leaves may be affected as badly as the most severely affected leaf shown in this illustration; on lemon leaves especially, the effects may be acute. The general symptoms of mild attacks are similar to those of zinc deficiency, but usually not so distinct, and, unlike zinc, the manganese deficiency is not usually associated with narrow and subnormal-size leaves. A typical cluster of lemon leaves affected with manganese deficiency is shown in figure 130. There are no fruit characteristics observed universally that typify this deficiency; a reduction in yields may result in mild to extreme cases. There are in California, on the other hand, many orchards in a very high state of production in which indications of manganese deficiency may usually be observed, to a small extent.

*Cause of manganese deficiency, and treatment.*—Manganese deficiency is often associated with soils which are high in native calcium content, or to which heavy applications of lime have been made, or with soils that are alkaline. Some of the soils of Florida, where this trouble is associated with marl, are definitely alkaline (Camp and Peech, 1939). Manganese exists in them in an unavailable form. In acid, sandy soils the deficiency is probably caused by prolonged losses of manganese by leaching, especially in areas of high rainfall.

Treatments by sprays of manganese sulfate neutralized with lime, as well as soil treatments of manganese sulfate, have been used successfully in Florida. Mixed fertilizers, with water-soluble manganese added, are procurable by the

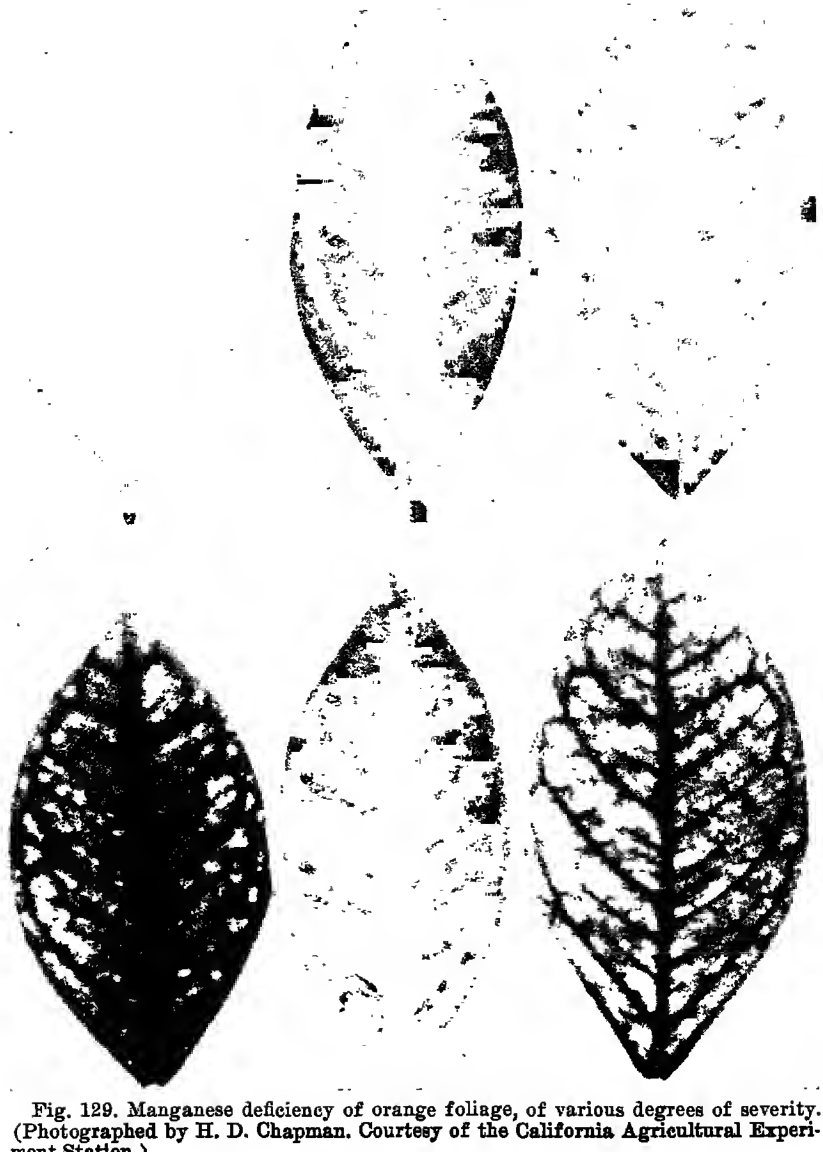

Fig. 129. Manganese deficiency of orange foliage, of various degrees of severity. (Photographed by H. D. Chapman. Courtesy of the California Agricultural Experiment Station.)

Florida orchardist. Possibly the practices in that state are to depend more on soil applications and less on sprays than formerly, since scale insects increase with abnormal rapidity on trees sprayed with manganese or zinc. Manganese sprays are therefore limited primarily to trees on alkaline soils where soil applications are unsatisfactory. Mixed fertilizers containing nitrogen, phosphorus, potassium, magnesium, manganese, and copper are now

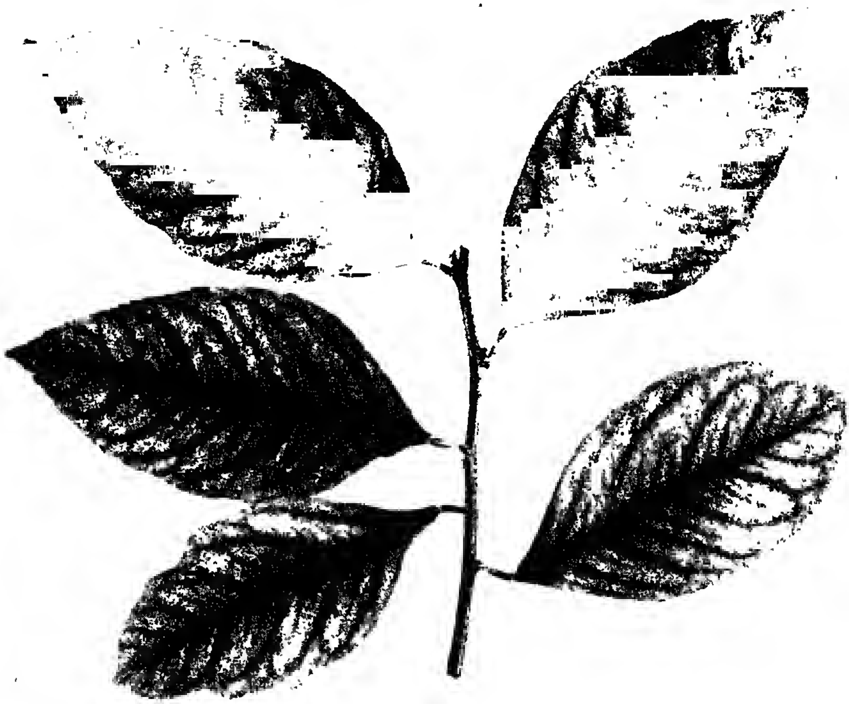

Fig. 130. Lemon foliage affected with manganese deficiency. (Photographed by E. R. Parker. Courtesy of the California Agricultural Experiment Station.)

obtainable in Florida, and are commonly used in conjunction with a zinc-copper spray to produce the most favorable nutritional conditions. Treatments in California have commonly consisted of spraying with manganese sulfate neutralized with either soda ash[1] or lime. But spraying with manganese should not be followed immediately by fumigation, since the trees may be injured by hydrocyanic acid gas. If one cycle of growth has been produced on the trees after the spraying, the fumigation may be done with less likelihood of foliage injury.

[1] A 3–1½–100 spray applied two years in succession may be more effective than a stronger spray applied only once.

### MINOR ELEMENTS IN RELATION TO RESISTANCE TO COLD

One of the most striking effects of a deficiency of any of the minor elements just discussed—and of magnesium, also—is a lessening of the resistance of citrus trees and fruit to cold (Lawless and Camp, 1940). The two freezes in Florida in 1940 gave vivid demonstrations of what occurs. In comparable plots at the Florida Citrus Experiment Station (Lawless, 1941) trees that were fertilized with ample amounts of nitrogen, phosphate, and potash were much more severely injured by the cold than trees that received this same basic fertilizer application plus magnesium, zinc, copper, and manganese. Table 30,

TABLE 30

EFFECT OF NUTRITIONAL CONDITIONS ON COLD INJURY IN PINEAPPLE ORANGES*

| Treatment | Injury | | Production in 1940–41 following January, 1940, freeze | |
|---|---|---|---|---|
| | Fruit damage | Leaf drop | Fruit of No. 1 and No. 2 grade | Total fruit per tree |
| | *per cent* | *per cent* | *per cent* | *pounds* |
| N-P-K | 94 | 89 | 45 | 160 |
| N-P-K+Zn+Cu | 79 | 75 | 88 | 166 |
| N-P-K+Zn+Cu+Mn | 84 | 71 | 81 | 172 |
| N-P-K+Mg | 91 | 69 | 71 | 258 |
| N-P-K+Zn+Cu+Mn+Mg | 65 | 39 | 86 | 327 |

* Summarized from Lawless, 1941, tables 2 and 4.

taken from a summary of these observations (Lawless, 1941), shows that the trees receiving all the minor elements, and therefore in a healthy and normal condition at the time of the freezes, also recovered more rapidly the next year. It seems apparent from these data that no one minor element alone increases the resistance to cold, but that when all three—zinc, copper, and manganese—are used, plus magnesium, a striking increase results.

## FERTILIZERS IN RELATION TO QUALITY (GRADE) AND SIZE OF FRUIT

### GENERAL CONSIDERATIONS

General consideration of fruit quality usually includes the external characteristics, such as smoothness or texture of the skin and freedom from blemishes, as well as the internal, such as thickness of skin and the eating qualities of the fruit. The eating qualities may be expressed with great exactness by stating the results of determinations of total sugar, total acid, the sugar-to-acid ratio, total soluble solids, and the like. The vitamin-C content is also important in determining the food value of the fruit. There can be no doubt that soil character affects the quality of fruits. Citrus is no exception to this general rule. To relate these differences to definite chemical elements which may be included in fertilizers is a difficult and complicated problem.

The quality of the fruit grown on an infertile soil is apt to be much more affected by fertilizers than the quality of the fruit grown on a relatively fertile soil. Certain elements of available plant food may be so deficient in an infertile soil as to produce unhealthy and abnormal tree conditions commonly associated with fruit of subnormal quality. Lack of a sufficient amount of nitrogen may be an exception to this general statement. Trees lacking nitrogen are commonly observed to produce very nearly a crop failure, so far as quantity is concerned, but nevertheless the fruit produced is notably smooth, thin-skinned, and of good quality. Applying fertilizer to a relatively fertile soil may be merely adding to the supply of essential elements, most of which are already present in abundance. Only when large doses of simple fertilizers are used separately can observations be made of their respective effects on quality. Studies have been made of the common elements of fertilizers such as nitrogen, phosphorus, and potassium.

### EFFECT OF COMMONLY USED FERTILIZERS ON QUALITY

*Nitrogen, phosphorus, and potassium.*—Some statements on the effects of nitrogen, phosphorus, and potassium on the quality of citrus fruit have been based on casual field observations, and a few have been dependent upon definite chemical analyses of the fruit. (For a review of the latter see Vol. 1, chap. vii, p. 764.) In general, it may be said that the applications of normal amounts of nitrogen, phosphate, and potash have not made very striking effects on the quality of the fruit, if one judges by the chemical analyses.

The effect of several different commercial fertilizers on the commercial quality of navel oranges in California was reported by Booth (1930) for five consecutive years. The fertilizers used separately in this experiment were tankage, sulfate of ammonia, cottonseed meal, a mixed fertilizer, and dairy manure. The fruit characteristics observed were size, commercial grade, and keeping qualities after grading, packing, and transportation to eastern markets under normal commercial conditions. The fertilizer materials had been applied in relatively liberal amounts for ten consecutive years before the observations were made.

The experiments were conducted on a Hanford gravelly loam, a soil type commonly used for citrus in California. It may safely be concluded from the data presented that these widely divergent fertilizer treatments did not make a significant difference in the size, commercial grade, or keeping quality of the fruit. The use of sulfate of ammonia, and also of cottonseed meal, did produce, on an average, slightly larger fruit than the other fertilizers. It is possible that the small size differences of less than 7 per cent can be attributed to casual variation of the trees and soil rather than to the effect of the fertilizers.

Low-nitrogen fertilization of Arizona grapefruit in the summertime (Martin, 1940) was associated with an increased proportion of smooth-textured fruit of superior market grades. Subsequent studies (Martin, 1942) showed that grapefruit trees having a high nitrogen nutrition throughout the year, and consequently a relatively high nitrogen analysis of the foliage in the fall,

were found to be less sweet, to color later, to be thicker-skinned and less well-shaped, as well as of a lower market grade, than fruit from trees having a declining nitrogen content through the latter part of the period of fruit growth and maturity. Later studies (Jones *et al.*, 1944) showed a relatively high (0.91) negative correlation between the nitrogen and ascorbic acid content of the juice of the grapefruit. It was concluded that the fruit from trees with a low nitrogen content produced fruit with 20 to 25 per cent more vitamin C than fruit from trees of a high nitrogen content.

Phosphate and potash, used in addition to a basic fertilizer treatment of farm manure, improved the commercial quality of grapefruit (Kinnison and Albert, 1936) in Arizona. The soil on which the experimental plots were laid out was high in calcium and low in available phosphorus.

A high potassium content of oranges was correlated with a thick rind and a high acid content (Anderssen, 1937); but a high phosphorus content was correlated with a thin rind and a low acid content. High nitrogen was correlated with high sugar content.

*Magnesium.*—Perhaps magnesium deficiency has had a more profound effect upon the internal quality of citrus fruit than any other essential element commonly used in fertilizers. A comparison of grapefruit grown on trees affected with magnesium deficiency with fruit from trees well supplied with this element (Cowart, 1942) showed that a lowering of the components that mainly affect internal fruit quality was associated with magnesium deficiency. The difference between such lots of fruit was detectable by taste. From chemical analysis it was also determined that the trees which had been treated with magnesium and had recovered from deficiency symptoms produced fruit higher in total soluble solids, total sugars, and vitamin C than trees affected with magnesium deficiency.

### EFFECT OF MINOR ELEMENTS ON QUALITY

Some of the most marked effects on citrus fruit quality have borne a relation to such minor elements as zinc, copper, and manganese. Applications of these elements have resulted in material increases (Cowart and Stearns, 1941) in acid, total solids, sugars, and vitamin-C content of the fruit, in comparison with fruit from trees fertilized only with nitrogen, phosphate, and potash. These differences were less, however, when magnesium was also added to the nitrogen, phosphate, and potash fertilizer applications. The subnormal conditions of quality have been clearly associated with the leaf symptoms of the respective deficiencies in the minor elements.

Experiments in California (Parker, 1937) showed that the commercial quality of grapefruit was noticeably poorer on trees affected with zinc deficiency than on trees sprayed with a zinc spray at the time of the bloom which produced the fruit. The sprayed trees also produced a greater quantity of uniformly larger fruit than the unsprayed trees. A summary of this work is shown in table 31 (from Parker, 1937). Extreme zinc deficiency (mottle-leaf) may account for extremely small fruit, as well as other abnormalities such as normal-size fruit with very thick skin and nearly devoid of juice. Typical

abnormalities are illustrated in figure 127. In the fruits shown, there was no other minor-element deficiency of consequence to complicate the comparisons.

## EFFECT OF FERTILIZERS ON SIZE OF FRUIT

Nitrogen probably has a greater effect on the size of citrus fruits than any of the other ordinary ingredients of fertilizers. There are indications that young fruits grow more rapidly on trees that are well supplied with available

TABLE 31

EFFECT OF ZINC TREATMENT OF GRAPEFRUIT TREES IN MARCH, 1934, ON THE 1934–35 CROP*

| Treatment | Total number of trees | Weight of fruit per tree | Fruit of Fancy and Choice grade per tree | Number of fruits per field box |
|---|---|---|---|---|
| | | *pounds* | *pounds* | |
| Untreated | 402 | 341 | 281 | 66 |
| Zinc-treated | 649 | 409 | 427 | 63 |
| Percentage: difference when untreated = 100 | ... | +20 | +52 | −5 |

* Data from Parker, 1937, p. 38.

TABLE 32

EFFECT OF ANNUAL CONDITIONS ON QUANTITY, COMMERCIAL QUALITY (GRADE), AND FRUIT SIZE OF WASHINGTON NAVEL ORANGES*

| Observations | 1929 | 1930 | 1931 | 1932 | 1933 |
|---|---|---|---|---|---|
| Average yield per tree, pounds | 59 | 124 | 104 | 96 | 81 |
| Percentage in Fancy grades | 70 | 94 | 61 | 72 | 72 |
| Percentage of desirable commercial sizes (220 per packed box or larger) | 70 | 38 | 40 | 34 | 50 |

* Condensed from Parker and Batchelor, 1942, pp. 29–31.

nitrogen. In California, applications of nitrogenous fertilizers have been made in the fall, with the idea of increasing the size of the fruit. Often, only a little of this nitrogen reached the root zone until enough rain fell to carry it down. (See p. 336, above.) Many growers in California believe that rains are especially effective in increasing the size of citrus fruits, and possibly one factor here is the movement of nitrates from the surface soil into the root zone. Certainly the fruit grows appreciably after rains, but we do not know just what would have happened to the fruit in a particular district had there been no rain. Soil moisture plays an important part in the size of citrus fruit; very small oranges have been associated with a lack of both moisture and nitrate in the root zone of the trees.

The volume of the crop also has an effect on the size of the fruits. Overloaded trees, especially mature ones, rarely produce large fruits. Young trees usually bear larger fruits than old trees. And fruits are larger in some seasons than in others. It is commonly observed that some seasons are characterized by fruit smaller than normal, and others by fruit larger than normal. These variations

in size are not necessarily correlated, to any marked degree, with fluctuations in the total number of fruits produced per tree. Apparently some other, intangible, climatic factor exists which has a notable effect on fruit size. Table 32 presents size data of Washington Navel oranges produced in California (Parker and Batchelor, 1942), showing the effect of season upon quantity, commercial quality (grade), and size of oranges. The trees had been consistently fertilized in the same way for several years. It is apparent that, with only relatively small fluctuations in weight of fruit produced per tree, there have been notable seasonal variations in the commercial quality of the oranges, as well as in their size. Such changes may mask results of fertilizer trials conducted for the purpose of determining the effect on fruit size and quality.

## TIME AND METHODS OF APPLYING FERTILIZERS

### MANURES AND BULKY ORGANIC FERTILIZERS

It is frequently asked whether animal manures should be applied fresh to citrus groves or whether they should first be composted. Growers ordinarily have no way to store manures except in piles in the open air. As the manure rots, great losses of nitrogen and organic matter usually occur. After the maximum original loss of total nitrogen by decomposition, the remaining 50 to 60 per cent of the total nitrogen is available only at a relatively slow rate. In other words, the most readily available part of the nitrogen, and of other constituents of the manure, is lost first. Whatever the respective merits of fresh and rotted manure, *ton for ton,* may be, trials based upon the original fresh weights have shown that plants have made much better growth with applications of fresh manure than with applications of rotted.

For manure to be most beneficial to citrus trees, it should be worked into the soil as soon as is practicable after application. If, however, the manure remains very dry there is very little loss.

It is generally thought that a good supply of available nitrogen in the soil is especially desirable in the spring, both for citrus and for other fruit trees. At this season, with the production of bloom, the growth processes of trees are particularly active. Furthermore, vigorous, healthy trees, if well supplied with nitrogen, tend not only to set relatively large crops, but also to hold the fruit relatively well during adverse climatic conditions. The soil may contain little available nitrogen in the spring, especially if a winter cover crop has been grown. A heavy spring application of ordinary manure, or of other organic material low in nitrogen, may render nitrogen unavailable to the trees at this time of the year. Where a large amount of nitrate exists in the soil, however, the time of applying manure may be of little moment.

In the southwestern part of the United States the navel orange tree is especially susceptible to a dropping of the young fruit, termed "June drop," which is increased by a deficiency of nitrates. The drop may take a heavy toll, especially when abnormally hot weather occurs soon after the blooming period. Hence it may not be desirable to apply low-grade bulky fertilizers in large quantities from the last of January until after this period of "June drop"

(Vaile, 1922). In California, probably the best time to apply bulky organic materials that are slowly available is in the late fall or early winter. Should there be any influence on the maturity of citrus fruits by rendering nitrogen unavailable, the effect then should be to hasten rather than to delay maturity. Furthermore, the price of manure may be lower in the summer and early fall than in the winter and spring, and the moisture content is apt to be much less, so that more actual manure is obtained when it is purchased by the ton. Where winter cover crops are grown, the manure can be applied and worked into the soil before the cover-crop seed is sown. If nitrogen in the soil is thereby rendered unavailable, it is possible that leguminous cover crops may be stimulated to obtain more nitrogen from the air than they otherwise would.

### NITROGEN

Nitrate nitrogen moves readily through the soil in the soil moisture; hence the most desirable method and season of application may vary greatly, depending on the rainfall and soil conditions. In the most extreme arid regions special methods of irrigation may have to be followed in order to promote the movement of nitrates into the citrus root zone. In humid sections special precautions in application may have to be taken to avoid excessive loss of nitrates by leaching. No universal rule for season or method of application can be stated. The application of nitrate salts especially should be timed with due consideration for the seasonal growth of the trees, the character of the soil drainage, the irrigation practice customarily employed, and the probable rainfall.

*Nitrogen in arid regions.*—In arid-region orchards that are irrigated in furrows, and in the absence of rain of any consequence, nitrates tend to accumulate in the surface soil. Consequently, where there are almost no summer rains there may be large surface accumulations of nitrates in heavily fertilized groves. The nitrate is carried into the root zone by the first rain of consequence. A good rain is then equivalent to a good fertilization with available nitrogen.

Where the soils are relatively impervious at shallow depths, the danger that the nitrates will be leached below the root zone is reduced to a minimum during years of normal rainfall, especially in groves where furrow irrigation is practiced. Under California conditions, commercial fertilizers may safely be applied in the late winter to get the benefit of the rains in moving the nitrates into the root zone.

Some California lemon growers make an early spring application of nitrogen fertilizer, followed by one or more applications in late spring and early summer, perhaps because it has been thought desirable to maintain a uniform supply of available nitrogen in the soil throughout the year. No experiments under field conditions have sustained such a belief. On the contrary, there are many good orange groves in California in which the nitrates fall to a low level while winter cover crops are growing, and which are fertilized only once a year.

Twelve years of fertilizer trials with Washington Navel oranges at the University of California Citrus Experiment Station (Parker and Batchelor, 1942) have failed to show any significant difference between applying nitrate

of lime once a year as compared with applying it three times a year. The same total amount was applied in both programs, and in such a way as to promote immediate penetration into the root zone.

In groves well fertilized *annually* where there is little probability of loss of plant food by leaching, it is questionable if the season of application is of much consequence.

*Nitrogen in humid regions.*—Soil and climate in so humid a region as Florida combine to make natural conditions conducive to loss of nitrate nitrogen by leaching. The light sandy soils and persistent summer rains make the loss one of the most important of all considerations in the economical fertilizing of citrus trees. The experience of many orchardists has justified applying nitrogen several times a year in Florida. Probably most of the orchards are fertilized three times a year—in spring, summer, and fall.

## PHOSPHATE AND POTASH

Phosphate and potash, particularly phosphate, are not so readily leached, even from sandy soils, as nitrogen; and in some soils it is difficult to get these fertilizers into the root zone. Their application should therefore be timed so as to take full advantage of rains. On the other hand, soluble phosphates may soon revert to less soluble forms, and potash may be fixed by base exchange. Comparatively little phosphate and potash are used in California citrus orchards. Where they are used, they may be applied once a year in mixed fertilizer. Phosphate is occasionally applied in the form of ammonium phosphate.

The common practice in Florida is to use phosphate and potash in mixed fertilizers in three applications a year. Such mixed fertilizers may have a 3–6–8 or a 4–6–8 ratio of nitrogen, phosphate, and potash. When magnesium, manganese, and copper are included in the mixture, the ratio of these six constituents, in order of their mention above, may be 4–6–8–2[1]–1–½. If this is combined with copper-zinc spray, plus dolomite when necessary (see "Calcium," p. 347, and "Magnesium," p. 351), the orchard will receive a fertilization favorable to general good maintenance.

## METHODS OF APPLICATION

*Concentrates.*—The methods of applying concentrated fertilizers to obtain maximum benefit depend chiefly upon soil and climatic conditions. In an orchard of young trees it is not necessary to fertilize the ground beyond the spread of the roots, but in the older orchards practically all the soil should be fertilized, as the roots of older trees are commonly found below the entire surface area. Concentrated materials are usually worked into the surface soil by disking. If they are used in the dry season, in orchards irrigated in furrows, they should be applied only in the irrigation furrows, since any of the fertilizer not actually covered by the irrigation water will not be carried into the root zone until rainfall occurs. Nitrates are readily moved by water, but ammonia is likely to be fixed by clayey soils so that water will not move it below the surface soil until it has nitrified. This applies in California and

[1] Water-soluble magnesium.

other areas where there is a relatively large amount of fine material in the soil; it is not so applicable to the extremely sandy soils of Florida.

When sulfate of ammonia or ammonium phosphate is used in the rainless season on heavy soils, and in irrigated orchards, it should be applied only in the irrigation furrows and the water should be run at least twice in the same furrows, with an interval of several weeks between irrigations. The first irrigation supplies moisture, which is requisite for nitrification, and moves the ammonia into the surface soil. Later irrigations carry some of the resulting nitrates down. Some growers make a practice of dissolving nitrates and ammonia compounds in the irrigation water, and with proper equipment this may be a very economical method of applying fertilizer.

The improper spreading of soluble fertilizers and soil amendments, or other materials such as zinc sulfate, often results in localized concentrations. Injury or death of citrus trees may follow although no excess of fertilizer has been applied; it was not properly distributed.

*Bulky materials incorporated in soil.*—Animal manures and other bulky organic materials may be spread broadcast and disked or plowed under. This method of application has the apparent advantage of enriching all or most of the area of the root system, and there is a likelihood of improvement of the physical condition of a correspondingly large area of soil.

Dairy manure is sometimes applied in trenches 10 to 12 inches deep. This practice is not so prevalent now as formerly, and trials conducted over twelve years (Parker and Batchelor, 1942) have shown that it is not so effective a method of application as spreading manure broadcast.

*Mulches.*—Mulches of various organic materials have been tried in citrus groves (Vaile, 1922) in connection with basin as well as furrow irrigation. Mulches of both alfalfa hay and of grain straw were used for five years in an experiment conducted at Arlington, California, by the California Citrus Experiment Station. The mulched plots received no cultivation, but the grain-straw plots required considerable hand labor owing to the growth of grain and weeds. The yields of oranges were relatively good, but mottle-leaf gradually increased. At the end of the five-year period the trees on all the mulched plots were so badly mottled that this method of culture was judged a failure. At best, mulching is wasteful of materials because of losses of nitrogen during decomposition, owing to the formation of volatile substances such as carbonate of ammonia. In dry weather the use of mulches is a fire hazard. Gophers and field mice may do much damage to the trees in mulched areas (see chap. xvi). In California some citrus trees are known to have been mulched for years with fair results. On the other hand, many trials with so-called permanent mulches have been given up. The results from using mulches will no doubt vary with the material used. There may be materials that could be used with benefit if there were practical means of overcoming the difficulties noted above.

## PURCHASE OF FERTILIZERS

The prices of commercial fertilizers depend both upon the kind of material and upon its constituents as indicated by chemical analysis. Commercial fer-

tilizers are usually sold on what is termed the "unit" basis, the unit being 1 per cent of a ton; each unit therefore consists of 20 pounds. Thus, with sulfate of ammonia analyzing 20 per cent nitrogen at $40 a ton, the nitrogen would cost $2 per unit; with dried blood analyzing 13 per cent nitrogen at $39 per ton, the cost of the nitrogen would be $3 per unit. Some growers also buy animal manures on the unit basis. Manure containing 1 per cent nitrogen and 40 per cent organic matter sold at a rate of $3 per unit of nitrogen and 3 cents per unit of organic matter would cost $3 for the nitrogen and $1.20 for the organic matter, or a total of $4.20 per ton.

When a mixed fertilizer is said to be compounded by a 6–8–10 formula, the figures refer to the units of total nitrogen, available phosphoric acid ($P_2O_5$), and available potash ($K_2O$), in the order mentioned. The available phosphoric acid is the water-soluble plus the ammonium-citrate-soluble phosphoric acid. The amount of each is usually indicated on the tag on each bag of mixed fertilizer. One with an 8 per cent available phosphoric acid might have 6 per cent water-soluble plus 2 per cent soluble in ammonium citrate. Available potash is that which is water-soluble.

## AMOUNTS AND PROPORTIONS OF FERTILIZER TO APPLY

Two aspects of the most desirable amount of fertilizer that may properly be applied to a bearing citrus grove should be considered: first, the amount that may be applied to induce greatest crop production, and, second, the amount that may be applied for greatest profitable returns. Applications of fertilizer will vary greatly with variations in such factors as the natural soil conditions, the past history of the grove, natural drainage conditions, rainfall, loss of nitrogen previously applied, amounts of fertilizer previously applied, location of present available amounts in the root zone, age of trees, and their present condition. Two of the most important factors, however, in determining the amount are the probable return for the fruit one or two years hence, when the effects of the current fertilizer practice will be realized, and the price of the fertilizer to be used.

### AMOUNT OF NITROGEN TO USE

Some investigators in California consider that there is generally no need of applying commercial nitrogenous fertilizer to bearing groves when the top three feet of soil contain from 60 to 120 pounds of nitrate nitrogen per acre early in spring. This would be equivalent to an average of 5 to 10 parts of nitrogen per million parts of dry soil. The amount of organic matter in the soil and the rate at which it nitrifies, as well as the size and condition of the trees, must be taken into account.

An extensive survey in California (Vaile, 1924) showed that the increase of nitrogen applications up to 350 pounds of actual nitrogen per acre for full-bearing groves was accompanied by increases in average yields. With larger applications there was an apparent decrease in yield. All groves that received as much as 350 pounds of nitrogen per acre per year were badly mottled.

It has been shown, however, that increased yields of oranges from pro-

gressively larger applications of nitrogen follow closely the law of diminishing increment (Spillman, 1923; Vaile, 1924; Parker and Batchelor, 1942). All crop increments from fertilizer applications do not follow this general law; but experience has shown that it should not be left out of account. Data from Parker and Batchelor (1942, p. 21), presented graphically in figure 131,

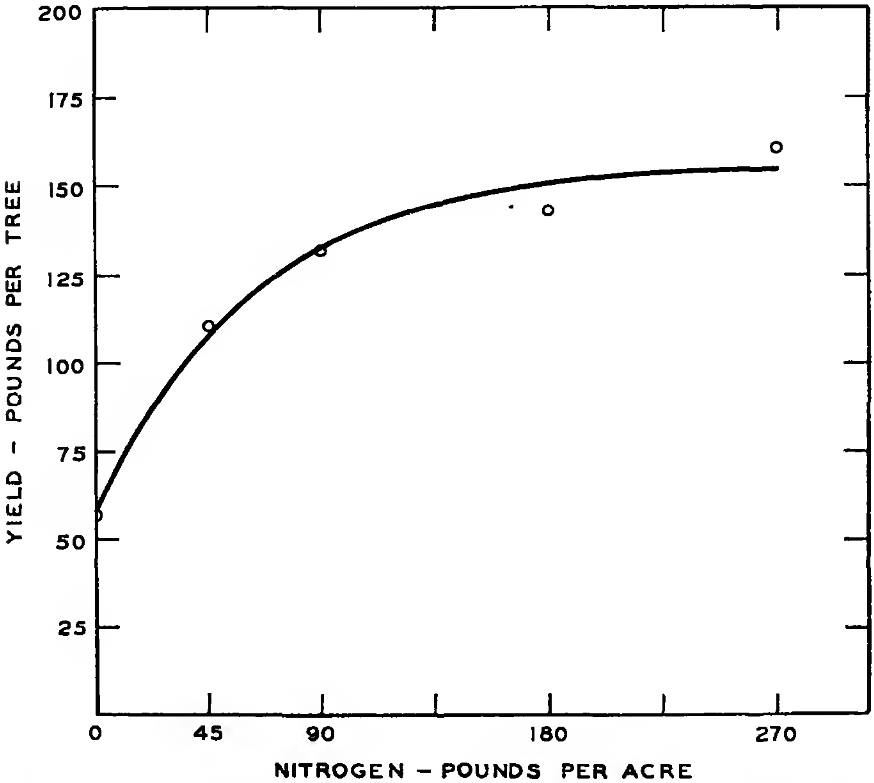


**Fig. 131. Production curve of oranges resulting from use of different amounts of nitrogen. (Data from Parker and Batchelor, 1942.)**

illustrate the fact that small applications of nitrogen make relatively greater increases, in yield per unit of fertilizer, than large ones. From the data in figure 131 the use of a single unit of fertilizer might be considered as 45 pounds of nitrogen per acre. The curve shows that in comparison with no fertilizer the first unit caused a larger increased yield than the second unit, whereas the second unit made a larger increased yield than the third and fourth units combined. It may still be profitable, however, to apply 150 pounds or more of total nitrogen per acre each year, when the price of fruit is high.

It is clear from figure 131 that the law of diminishing returns may very rapidly reduce the profit from the expenditure of relatively large amounts of

money for fertilizer. The amount of money which it is wise to spend for fertilizer will vary from time to time as the price of fruit and the price of fertilizers fluctuate. When fruit is at low level it becomes economically sound to spend less money for fertilizer than when fruit is high-priced. The experiences of many successful citrus growers in California seem to justify applying annually 180 to 250 pounds of nitrogen per acre.

Any figures that might indicate the most profitable amount of fertilizer to apply, as reflected in the net profit per acre, would be of little permanent value except as an illustration of the law of diminishing returns as applied to fertilizer purchase. They would be based entirely on present land valuations, present price of fertilizer, present additional operating costs, and past selling prices of fruit. Since all these factors may change, the final result in net income will also change.

A clear understanding of all the factors involved, however (Vaile, 1924), should be one of the chief considerations in guiding a farmer in the expenditure of money for fertilizer.

### PROPORTION OF PHOSPHATE AND POTASH TO NITROGEN AS PRACTICABLE TO USE

Some citrus growers in California use commercial mixed fertilizers containing nitrogen, phosphorus, and potassium. Applications of organic materials from outside sources also supply appreciable amounts of phosphorus and large amounts of potassium. As a result of several field trials on various types of soil, Parker and Batchelor (1942) found no definite evidence to show that it is necessary to apply, in most citrus districts of California, compounds containing phosphorus or potassium as supplied in commercial fertilizers.

Recommendations for Florida indicate that it has become rather general usage to apply as much potash as phosphate, or more, and more phosphate than nitrogen. Some of the most widely used mixed fertilizers have had the following ratios of nitrogen, phosphate, and potash, respectively: 3–6–8, 4–6–8, and 3–8–8. When magnesium, manganese, and copper are applied to the soil in Florida, which is the usual method of using these materials there, the mixed-fertilizer formula will provide for six elements. The requirements of the common usage would be met by the basic ratio 3–6–8–2–1–½, where the figures represent units of N, $P_2O_5$, $K_2O$, MgO, (water-soluble) MnO, and CuO, in the order mentioned.

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## CHAPTER VIII

# COVER CROPS AND GREEN MANURES

BY

LEON D. BATCHELOR

COVER CROPPING is the practice of growing a pure or mixed stand of densely spaced herbaceous plants to cover the soil for part or all of the year. The plants may be incorporated into the soil by tillage, as in seasonal cover cropping, or they may be retained as a protection in reducing the risk of injury from soil erosion—an important consideration in many hillside orchards. On some soil types and in districts subject to torrential rains the use of cover crops is essential to prevent irreparable damage from soil erosion.

When plants are incorporated into the soil by tillage the organic matter thereby added to the soil is called "green manure," and the practice is sometimes termed "green-manuring." Cover crops may thus be used as green manures. Other plant materials, however, such as alfalfa hay and bean straw, may be brought into an orchard to be spread and then worked into the soil to serve as green manures, though such materials, originating outside the orchard, are more commonly known as bulky organic fertilizers. Thus, although seasonal cover cropping and green-manuring are often treated as essentially the same thing, there is a distinction between them.

The value of cover cropping as a cultural practice in fruitgrowing has long been recognized in America. The growers of deciduous fruits of the eastern states were mindful of the value of cover crops many years before their use became common in the California citrus orchards. The general practice of the enrichment of farm lands by green-manuring, however, is as old as the literature on agricultural subjects. It was highly recommended and was apparently a well-established practice in China, Greece, and the Roman Empire long before the beginning of the Christian Era.

In reviewing the increasing tendency to use cover crops in California citrus orchards, Vaile (1924) states that from 1914 to 1924 the use of winter green-manure crops in citrus groves increased materially. In the winter of 1914–15 it was estimated that less than 40,000 acres of citrus orchards in California were planted to green-manure crops of any kind. Nearly half this acreage was planted to cereal crops. In 1915–16, approximately 67,000 acres were planted to leguminous green-manure crops; in 1916–17, approximately 100,000 acres. In the years from 1934 to 1945 the acreage varied, and there was probably a decline in the total amount.

In some citrus-growing areas, as in Florida, it is desirable to grow a cover crop in summer because this is the season of greatest rainfall. In other areas, as in California, winter is the time of greatest rainfall and possibly the only season when it is practical to grow a cover crop. There are large irrigated areas in California for which the water supply is insufficient to grow a cover crop and to provide for the moisture requirements of the trees in summer.

On the other hand, there are limited areas for which irrigation water is abundant and cheap; there, it is frequently practical to grow two cover crops each year, one in summer and one in winter. The most favorable time to grow a cover crop, and for the crop to grow, will depend upon local conditions as well as upon the season of growth, and will vary widely in the various citrus-growing areas.

## THE FUNCTIONS OF A COVER CROP

The primary functions of a cover crop in an orchard are to improve the soil structure, to prevent soil erosion, to improve nutritional conditions for the trees by rendering nutrients in the soil more available, and to remove excess water from heavy soils in years of excessive rainfall. These functions will not commonly operate with equal importance in any one orchard.

The improvement in soil structure following the growth of cover crops is an everyday observation of farmers in general. Most noticeable, usually, will be a quicker passage of irrigation water into the soil, or the greater ease with which the soil is tilled. The more mellow, friable condition of soils frequently cover-cropped, in comparison with soils kept continuously in a state of clean culture, sometimes presents a striking contrast. The periodical lack of cultivation that is associated with any annual cover-cropping practice—cultivation being discontinued for four to six months of each year—is probably an important factor in restoring soils to more nearly their original structure.

Soil erosion in hillside orchards can often be more surely prevented by the growth of a cover crop than by any other practical means. Some soil types are so erodible that even with a grade of only 3 to 5 per cent there will be an appreciable loss of topsoil if land is left bare during the rainy season. Erosion will be especially critical if floodwaters from adjacent lands or highways pass over bare orchard soil soon after it has been cultivated. Even a small amount of cover crop or weed growth has a tendency to spread the movement of surface water and slow down its rate of flow, and thus greatly to reduce its erosive power. Many desirable orchard sites thus require a cover crop throughout the rainy season; indeed, the practice is known to have improved the vigor and productiveness of citrus trees in many orchards.

Cover cropping is often the most practical method of procuring organic material. The beneficial effects of applying organic material to soils for the growth of both annual and tree crops has been recorded for many orchards (see chap. vii). The relative benefits vary with soil type, fertilizer treatments previously applied, conditions of culture, and the primary crops grown after the cover crops. Where the use of organic matter apparently improves the fertility of the soil, the growth of a cover crop is usually the most economical way to obtain a fair amount of it. In some citrus-growing districts bulky organic fertilizers are much higher in price than other fertilizer materials; if natural rainfall or relatively cheap irrigation water can be used to produce the cover crop, this may mean a consistent saving in operation costs.

In citrus districts of California in which the winter rainfall is fifteen to twenty inches or more annually, there will be an excessive amount of soil moisture in the root zones of citrus trees for some time if the trees are on rather heavy soil of high water-holding capacity, especially if the subsoils are relatively impermeable in comparison with the surface soil. These conditions are common for hill lands that are nearly free from frost hazard and are otherwise desirable for such crops as avocados (Huberty and Pillsbury, 1943) and citrus. The risk for citrus orchards is somewhat reduced by the practice of growing a cover crop during the rainy season, since it has been proved helpful in removing excessive soil moisture the prolonged presence of which would be injurious to citrus trees. A rapid-growing cover crop, such as mustard, is more desirable under such conditions than some of the slower-growing legumes.

## FACTORS INFLUENCING DECOMPOSITION OF COVER CROPS

In order to make the most effective use of cover cropping as one of the means of maintaining soil fertility, it is desirable to understand the several factors which influence the decomposition of cover crops.

The decomposition of cover crops, as of any other organic matter in soils, is caused by soil microörganisms that use the organic matter as food. In the process of decomposition, various organic compounds are broken down to produce a number of by-products. Of the by-products, those most important to the farmer are carbon dioxide, amino acids, and ammonia, the last two of which are quickly converted into nitrates.

Several factors influence the nature and rapidity of plant decomposition. It is not practicable to review here the many investigations that have been made. Those of Waksman and Tenney (1928), however, as they bear upon the practical handling of a cover crop, may be summarized somewhat as follows:

*The nature of the plant.*—The composition of different plants varies and influences the decomposition processes markedly. "Some plant constituents may decompose more readily than others; some substances may even retard the decomposition of other substances" (Waksman and Tenney, 1928, p. 170).

Materials such as clover, alfalfa, manure, and green mustard plants, which are high in nitrogen in comparison with carbon, decompose readily. Materials such as cereal straw, leaves, and cornstalks, which are relatively low in nitrogen, decompose slowly.

The decomposition of this latter class of materials, when they are applied to orchard soils, usually proceeds so slowly that the microörganisms actually use up the nitrates which are already present in the soil at the time the applications are made. Thus there may be a decided depression of the nitrates in a soil, following the application of cereal straw. The extent and duration of this depression will depend on many factors, such as the relative amount of organic matter applied, the carbon : nitrogen ratio of the material, the conditions of soil moisture, the soil temperature, the amount of nitrate pres-

ent in the soil, and the character of the soil. If a cereal is used as a cover crop and allowed to mature before being plowed under, the depression of the nitrate content of the soil may last for many weeks.

On the other hand, the working under of a succulent legume or of a crop of high nitrogen content, such as a mustard cover crop before it matures enough to bloom, will be followed by a relatively rapid increase in the nitrate content of the soil. If soil and weather conditions are favorable for rapid decomposition of the organic matter, there will be only a brief temporary depression of nitrates in the soil when materials that are high in nitrogen are used.

The presence of sizable amounts of cereal straw, shavings, or sawdust in manure may greatly retard the decomposition of the material. The plowing under of such manure with a cover crop may also retard the decomposition of the cover crop.

*The age of the plant.*—"The younger the plant and the less mature it is, the more rapid will be the rate of its decomposition. The decrease in the relative nitrogen and ash content and of the total water-soluble substances and the increase of the cellulose and lignin content, with an increase in maturity of the plant will account for its slower decomposition" (Waksman and Tenney, 1928, p. 170).

It is clear, therefore, that the plowing under of mature and woody cover crops which have gone to seed may depress the nitrates in the orchard soil. The depression may persist for several weeks even though the cover crop is a legume. The relative amount of nitrogen in a legume crop, in comparison with the carbon content, is higher before the plants reach maturity than during the late blossoming and seed-forming period.

Bal (1922, p. 141) studied nitrate production as influenced by the age of Crotalaria plants incorporated into the soil. He found the relative rapidity of nitrate formation to be as follows:

| *Age of plants (weeks)* | *Total nitrogen nitrified* | |
|---|---|---|
| | *After two weeks (per cent)* | *After six weeks (per cent)* |
| 2 | 56.26 | 78.00 |
| 4 | 36.73 | 51.58 |
| 6 | 24.09 | 32.12 |
| 12 | 1.06 | 13.02 |

It is evident that plants 2 to 4 weeks old nitrified rapidly, whereas those 12 weeks old were very slow to nitrify.

This problem was also investigated by Martin (1921, p. 156), who reviews the conclusions of some of the previous investigators. In his review five different investigations are cited, all of which confirm the principle that the greater the succulency of the material studied, and the greater its nitrogen content relative to other constituents, the more rapid is the decay. The experiments were carried on with both legume and cereal plants. Martin concludes from his own investigations that, "using as measurements the rapidity of humus formation, the accumulation of nitrates, and the increased availability

of the plant nutrients, the subsequent crop growth proved that the greatest rapidity of decomposition and the greatest benefit to the soil were achieved by the use of green manures at the half-grown stage."

Inasmuch as the nitrogen content has so important an influence on the subsequent decomposition of the cover crop, the stage of growth at which the nitrogen content is greatest is of direct interest to the fruitgrower. Martin (1921, p. 156) studied rye, oats, and buckwheat, and concludes for all three that "the younger the organic matter used, the larger is the percentage of total nitrogen present therein." In summarizing the observations of several investigations, Pieters (1927, p. 78) states that the studies of crimson clover, red clover, alfalfa, and hairy vetch warrant the general conclusion that the percentage of nitrogen is highest at a relatively early stage of growth. However, the total nitrogen produced by the entire crop is greatest at or a little after blooming time.

From the above-mentioned investigations, and others which confirm them, it is safe to conclude that a cover crop in an immature, succulent state will decay more rapidly than a mature crop.

## EFFECT OF COVER CROP ON PHYSICAL CONDITION OF SOIL

*Soil structure.*—The incorporation of a cover crop, or the addition of any organic matter, affects the structure of most soils. The principal effect appears to be a higher percentage of water-stable aggregates than exists in soils to which no organic matter is added. The effect of mixing the tops of the cover crop with the tilled soil cannot be separated from the beneficial effect of the cover-crop roots, which extend also below this layer of soil. Probably both are important, especially in the improvement of the physical condition of heavy soils. Soils that are cover cropped annually are friable, easily tilled, and readily distinguishable, by general field observation, from comparable soils that have been subjected to a continuous system of clean culture.

The maintenance of the original structure of the soil is important in orchards in both irrigated and humid regions. One of the most obvious effects of cover cropping observed by fruitgrowers in irrigated regions is that this practice is usually followed by a more rapid penetration of irrigation water. The presence of a cover crop in the orchard during the rainy season also reduces the loss of water by excessive runoff and temporarily improves the soil conditions in the orchard, being somewhat comparable to the establishing of a sod on the land. The benefit of sod in improving soil structure has been noted by farmers and scientific observers for many generations.

*Organic content of soil.*—One cannot expect to increase the organic content of the soil in a citrus orchard materially or permanently either by cover cropping or by applying large amounts of organic matter. The value of organic matter in the soil must therefore be explained as in some measure a result of the beneficial effect of its temporary presence and its disintegration in the soil, rather than of its accumulation.

A good tonnage of cover crop, such as 10 tons green weight per orchard acre, would add only 0.11 of 1 per cent organic matter to the surface 9 inches of soil. A heavy application of ordinary dairy manure, such as 15 tons per acre, would, on the average, add only about 0.25 of 1 per cent organic matter to the surface 9 inches of soil. The addition of such small amounts of organic matter, relative to the volume or weight of the surface 9 inches of soil, is certain to have only a limited influence on the water-holding capacity of the soil. Even though such additions were made yearly for several decades, the sum-total gain in organic matter would be exceedingly small. Cultural operations and the long, warm summers in the citrus-growing areas are conducive to the rapid loss of organic matter through the maintenance of conditions favorable for the growth of microörganisms of the soil, which persistently decompose the organic matter.

In contrast, a climate favorable to the actual gain in organic carbon in the soil might be expected in England. Dyer (1902, p. 29) reports, however, that the experiments conducted on the Broadbalk wheatfield do not show notable gains. Plot 2b, which had received 14 long tons of manure per acre annually for 50 years, contained, in 1893, 2.230 per cent organic carbon in the surface 9 inches of soil. At the same time, the soil of plot 9a, which had received a complete inorganic fertilizer only, contained 1.162 per cent organic carbon. Thus, plot 2b showed a gain, over plot 9a, of only 1.068 per cent organic carbon in the surface 9 inches of soil after a 50-year period of annual applications of relatively large amounts of organic matter. The organic carbon contents per acre in the surface 9 inches of these soils at the end of 50 years' continuous experiments were: plot 2b, 52,046 pounds; and plot 9a, 30,126 pounds. Plot 2b thus exceeded plot 9a by only 21,920 pounds, after receiving a total of 1,568,000 pounds of manure per acre during the five decades. The two plots had produced similar yields of wheat, namely, 35 to 40 bushels per acre annually, over the 50-year period.

Another illustration of the failure of notable amounts of organic matter to accumulate in soil treated regularly with organic fertilizer may be taken from the "Rubidoux" experiments of the California Citrus Experiment Station. In these experiments orange and lemon trees were planted on adjacent plots F and G in 1907. For 23 years plot F received an average annual application of 15 tons of manure per acre. This manure contained approximately 175,000 pounds of organic matter. In this same period plot G received only a negligible amount of organic matter applied in dried blood and steamed bone meal. Winter cover crops were grown annually on both plots, however, in the last seven years of the 23-year period. Soil samples taken at the end of the 23-year period show that the surface 12 inches of soil of plot F contained 0.890 per cent organic carbon, and of plot G 0.334 per cent. This amounts to a gain of only 0.556 per cent organic carbon in the surface foot of soil after a prolonged period of relatively heavy applications of an organic fertilizer.

In a 7-year trial of cover crops conducted by the Florida Experiment Station in an orange orchard, Stokes *et al.* (1932) reported no increase in the "decomposed organic matter." Even after incorporating the equivalent of an average of 4,969 pounds of air-dried top growth of Crotalaria per acre each

year for seven years in succession, no increase in decomposed organic matter was found in the upper 8 inches of soil. The authors conclude (p. 16): "The results indicate a slight decrease in the 'decomposed soil organic matter' of the surface 8 inches of soil from 1925 to 1932, despite the return of large quantities of rough organic matter in the form of summer cover crops."

Senstius (1925, pp. 149–155) has directed attention to the fact that no organic matter accumulates in well-drained, well-aerated soils when the average temperature is 25° C. (77° F.) and higher, as in most tropical lowlands. Soil temperatures under most citrus-orchard conditions are above this point for many weeks in succession. In an orange orchard in Riverside, California, in 1928, the soil temperature one foot below the surface of the ground rose above 76° F. on May 25 and remained above that temperature until October 11. During this period of 20 weeks the soil temperature fluctuated between 76° and 88° F. Higher temperatures existed in the surface 9-inch layer of soil, in which most of the organic matter from manure and cover crops is incorporated. Under such conditions, favoring maximum bacterial action, organic matter is disintegrated very rapidly.

From the point of view of the citrus grower who has to irrigate his orchard, the addition of organic matter to soil by cover cropping may be justifiable, both for the improved physical condition of the soil and for the probable increase in fruit production. The increase in organic carbon content of the soil may be relatively small, but the improvement in soil structure makes it possible to irrigate more satisfactorily.

## NITROGEN FIXATION

In citrus culture an important practical consideration is the effect of nitrogen compounds in the soil upon the nitrogen-fixing power of legumes, in view of the fact that nitrogen compounds are so much used in fertilizing citrus trees.

Numerous experiments have been carried on to demonstrate the power of legumes to obtain from the air the nitrogen necessary for their growth. Such experiments have been conducted with soils or sand cultures devoid of available nitrogen at the beginning of the experiment.

Many observations have been made under field conditions, in an attempt to measure the amount of nitrogen actually added by the growth and incorporation of a legume cover crop in a soil. In summarizing several observations in this regard, Hopkins (1910, p. 217) states: "Clover and other legumes take available nitrogen from the soil in preference to the fixation of free nitrogen from the air, the latter being drawn upon only to supplement the soil's supply and thus balance the plant-food ration. . . . the conclusion may be drawn that on normally productive soils at least one third of the nitrogen contained in legume plants is taken from the soil, not more than two thirds being secured from the air. . . . When grown on richer soils, such legume crops leave the soil poorer in nitrogen; but on poorer soils, furnishing less than the normal amount of available nitrogen, the growing of such legumes would enrich the soil in proportion to its poverty."

The subject of symbiotic nitrogen fixation, as influenced by the nitrogen in the soil, has been investigated by Albrecht (1920, p. 316), who concluded, after numerous trials, that "nitrogen fixation will take place in a soil containing large amounts of nitrogen in the form of either nitrates or organic matter." According to the data given in his report, variations in the amount of total nitrogen in the soil failed to exert any varying influence on the amount of nitrogen fixed.

The results of other investigations indicate that relatively small amounts of available nitrogen in the soil may assist the fixation of atmospheric nitrogen by giving the legumes a good start in the early stage of their growth. According to the findings of Giöbel (1926, p. 119), however, relatively large amounts of available nitrogen in the soil may affect adversely or altogether inhibit the fixation of nitrogen from the air by legumes. This author lists 181 publications dealing, in large part, with legumes and nitrogen fixation. The majority of the investigations reviewed show that relatively large amounts of available nitrogen in the soil depress the nodule formation on the various legume crops and thus reduce nitrogen fixation materially. In reporting his own investigations following a large number of experiments with alfalfa, Giöbel states (p. 118): "The amounts of nitrogen fixed, in all cases, were inversely proportional to the amounts of soluble soil nitrogen at the disposal of the plants." The same observations were generally true with soy beans.

These findings have a direct bearing on the choice of a cover-crop plant. Legume crops such as clover or vetch have been used extensively as cover crops in citrus orchards. That they have the power of fixing nitrogen, as well as of supplying organic matter, in an impoverished soil, has been proved beyond question.

## EFFECT OF COVER CROPS ON CITRUS ORCHARDS

The incorporation of organic matter into the soil, either by the use of manure as fertilizer, or by the disking under of a cover crop, is an essential part of good farming methods in a tilled orchard. In reviewing several field trials in California citrus orchards, Vaile (1922, p. 512) concludes, however: "The use of winter green-manure crops has been followed by conflicting results in the different trials. In one case a marked increase in yield and an improvement in tree condition resulted; in a second case there was a slight decrease in yield; in a third case the results seemed to be negative. The failure of the cover crop to always produce increased yields can apparently be accounted for in some cases, but has not been in other cases."

*Examples of beneficial effects.*—One of the most striking illustrations of the beneficial results of the use of cover crops was the recovery of devitalized trees both of oranges and of lemons on the Rubidoux experimental plots of the California Citrus Experiment Station. The trees on these plots were planted in 1907 and grown until the fall of 1923 under clean-culture conditions. During the latter part of this period the trees gradually declined in vigor and failed to produce the increase in yield expected by reason of the increase in age. A cover crop of purple vetch was planted in the fall of 1923 and plowed under

in the spring of 1924. After that time, a winter cover crop was grown annually, and the productivity of the trees increased progressively during the following six years.

The increase in yields was not so striking, however, as the change in the general appearance and vigor of the trees after the six years of cover-cropping practice. The "mottle-leaf" condition, which had been extremely bad, was greatly improved, and the size and vigor of the annual twig growth increased radically. An idea of the density and general appearance of the trees before and after the cover cropping may be gained by comparing figures 132 and 133. The tree pictured in these photographs was in the area fertilized with a complete fertilizer. In these trials the striking improvement of the trees soon after leguminous winter cover crops were grown seemed out of all proportion to the tonnage of organic matter turned under.

Beneficial effects of the use of cover crops in an orange grove have also been reported from Florida by Stokes *et al.* (1932, p. 15). These authors concluded, after a 7-year trial: "Larger cover crop yields have meant a faster tree growth and larger fruit yields for the duration of the experiment. Clean culture has little or nothing to recommend it as a grove practice on this type of soil." These conclusions were reached after comparing the effect of several different cover crops with that of clean culture in which mixed commercial fertilizers were used as part of the cultural treatment. No bulky organic fertilizer materials were applied in addition to the cover crop. Some of the fruit yields obtained in the Florida trials are summarized in table 33 (p. 394). Of the several summer cover crops used, Crotalaria gave the best results. In comparison with the cover-cropped plots, the clean-culture plots were practically failures.

Observation of the effect of winter cover crops on orange yields, in comparison with clean culture using various fertilizer materials, has been continued at the California Citrus Experiment Station since the Rubidoux trials previously mentioned. At the beginning of the experiment, the orchard of navel oranges was ten years old. Nine winter cover crops and two summer cover crops, together with the straw from four intercrops of beans, had been incorporated into the soil of this grove in the decade before the cover-crop trial began. In table 34 (p. 394) the results of a 17-year trial are summarized.

Legume cover crops, or a mixture of a legume and mustard, were used annually, 6 to 10 tons of green weight per acre being incorporated into the soil yearly. During the first twelve years of the experiment (1928–1939), all the plots were fertilized at the annual rate of one pound of actual nitrogen per tree (this is equivalent to 90 pounds per acre). During the last five years of the experiment (1940–1944) the rate of fertilization was increased threefold. The cumulative benefits of the cover cropping of the entire orchard before this trial began masked the effect of cover cropping somewhat during the first four years of the trial (table 34). It is apparent that the cover crops had a beneficial effect only where the concentrated inorganic fertilizers were used. Where manure was used as the only fertilizer material, the cover crops had a depressing effect on yields during the first twelve years, and little if any effect during the last five years.

Fig. 132. Orange tree seventeen years old, fertilized with "complete" fertilizer and grown under "clean-culture" conditions until the first cover crop was produced, as shown. Photographed in February, 1924. Compare with figure 133.

When combined with moderate applications of nitrogen from concentrated sources, the winter cover crops were consistently beneficial, to some degree, regardless of the type of nitrogenous fertilizer used. The organic matter added

Fig. 133. The same orange tree as that shown in figure 132, after six years' culture with annual winter cover crops.

by the cover crops apparently maintained a more favorable carbon : nitrogen ratio for the growth of the orange trees, as measured by crop production and general vigor of the trees. When the nitrogen applications were trebled, during the years 1940–1944, it became apparent that the added organic matter

was of increasing importance with certain fertilizers, especially with the complete fertilizer and sodium nitrate. With the latter, in the plots which were not cover cropped the soil structure deteriorated rapidly in the last five-year

TABLE 33

AVERAGE YEARLY FRUIT YIELDS OF PINEAPPLE ORANGES FROM TREES OF COVER-CROPPED AND CLEAN-CULTURED PLOTS DURING THEIR FOURTH, FIFTH, SIXTH, AND SEVENTH YEARS OF AGE*

| Cover crop | Pounds of fruit per acre of 70 trees each | | | | | Yield increase, cover-cropped trees over clean-cultured |
|---|---|---|---|---|---|---|
| | 1928 | 1929 | 1930 | 1931 | Total | *per cent* |
| Crotalaria | 360 | 448 | 6,088 | 6,664 | 13,560 | 424 |
| Velvet beans | 64 | 168 | 3,224 | 5,720 | 9,176 | 287 |
| Beggarweed | 312 | 592 | 1,944 | 7,984 | 10,832 | 339 |
| Natal grass | 304 | 616 | 3,944 | 7,712 | 12,576 | 393 |
| None (clean culture) | 16 | 112 | 2,304 | 768 | 3,200 | ... |

* Reconstructed from table VI of Stokes *et al.* (1932, p. 14).

TABLE 34

EFFECT OF WINTER COVER CROPS ON NAVEL ORANGE YIELDS

| Treatment[a] | Average annual yield per tree (pounds) | | | |
|---|---|---|---|---|
| | 1928–1931 | 1932–1935 | 1936–1939 | 1940–1944 |
| Urea and cover crop | 114 | 138 | 117 | 150 |
| Urea | 111 | 126 | 92 | 133 |
| Increase in yield, owing to cover crop (*per cent*) | *3* | *10* | *27* | *13* |
| Calcium nitrate and cover crop | 122 | 158 | 120 | 189 |
| Calcium nitrate | 112 | 113 | 96 | 154 |
| Increase in yield, owing to cover crop (*per cent*) | *9* | *40* | *25* | *23* |
| Sodium nitrate and cover crop | 114 | 149 | 121 | 147 |
| Sodium nitrate | 110 | 120 | 93 | 75 |
| Increase in yield, owing to cover crop (*per cent*) | *4* | *24* | *30* | *96* |
| Complete fertilizer and cover crop | 114 | 150 | 113 | 142 |
| Complete fertilizer | 112 | 134 | 102 | 101 |
| Increase in yield, owing to cover crop (*per cent*) | *2* | *12* | *11* | *41* |
| Dairy manure and cover crop | 107 | 130 | 80 | 171 |
| Dairy manure | 119 | 140 | 122 | 172 |
| Decrease in yield, owing to cover crop (*per cent*) | *10* | *7* | *34* | ... |

[a] Nitrogen supplied at the annual rate of 1 pound per tree, 1928–1939; 3 pounds, 1940–1944.

period. This, in turn, had an adverse effect on the penetration of the irrigation water and rainfall into the soil and caused a persistently detrimental effect upon the vigor of the trees and crop production. Soil studies (Aldrich, Chapman, and Parker, 1944), and also the yield data presented in table 34, have shown the impracticability of growing oranges under clean-culture conditions with such liberal applications of concentrated fertilizers.

*Factors bearing on the varying responses of citrus trees to cover cropping.*—Soil types and climatic conditions no doubt have a bearing on the results that may follow the use of cover crops. When grown in the heavy clay loam soils in several of the coastal sections of California, winter cover crops are apparently beneficial as a means of removing surplus soil moisture during and at the end of the rainy season in late winter. At this cool, damp season of the year, citrus trees are in a semidormant state and their demands for soil moisture are relatively low. Clean-cultivated orchards under these conditions, however, retain an almost constant, relatively high soil-moisture content for rather long periods. Many casual field observations indicate that citrus trees in such orchards may be greatly benefited by winter cover crops.

Where soils are already rich in nitrate, the growth of a cover crop may be a means of preventing loss by leaching. This is no doubt important with respect to permeable soils in regions of heavy rainfall.

In California relatively large supplies of various kinds of manures are available. Partly for this reason, manures are widely used in citrus orchards throughout the State. Vaile (1924) observes, however, that the value of cover crops is most pronounced in orchards fertilized with comparatively small amounts of manure or other organic fertilizers. He states further: "It seems probable, therefore, that the persistent use of green-manure crops will relieve the growers of the necessity of applying such liberal applications of manure."

A yield of ten tons of cover crop (green weight of tops) to the orchard acre is considered a good yield. This may contain as much nitrogen as the same weight of ordinary dairy manure, and as much organic matter as eight tons of manure. It is to be expected, therefore, that cover cropping may be considered somewhat as a substitute for the application of bulky organic fertilizers.

The literature on the benefits of cover cropping, as measured by the increased production of subsequent crops grown on the same land, is mainly limited to reports of the benefits to annual crops. These cannot safely be taken as literally comparable when applied to tree crops. There is a notable absence of reliable information on the value of cover cropping citrus and deciduous orchards. The value of using a bulky organic fertilizer as a source of part of the plant food applied to citrus orchards has been more definitely demonstrated. After surveying the cultural and fertilizer practices of six hundred citrus orchards, Vaile (1924) concluded that the largest average yields resulted when the largest proportion of the nitrogen was carried in "bulky manure."[1] Such materials as bean straw, manure, and alfalfa are relatively expensive sources of nitrogen, however, when compared with chemical fertilizers. The greatest economic value of a cover crop may therefore be as a supplementary source of organic matter to replace part, at least, of such bulky, more costly fertilizers as organic manures. Since cover cropping is part of the cultural practice in many successful citrus orchards, it may well be tried for this purpose, especially in any district where the price of bulky fertilizers is high in comparison with that of inorganic fertilizer materials. The practica-

[1] The term "bulky manure," as used by Vaile (1924), includes hays and straws as well as animal manures.

bility of thus employing it is dependent, however, upon there being an adequate supply of irrigation water available at a reasonable cost, so that the growth of the cover crop is economical.

## PRACTICAL CONSIDERATIONS IN CHOICE OF COVER CROP

*Tonnage of organic matter produced.*—The value of cover crops in maintaining fertility in citrus orchards is dependent, in part, upon the production of reasonably heavy tonnages of organic matter. The addition of nitrogen by

TABLE 35

AVERAGE COMPOSITION OF SEVERAL WINTER (LEGUME) COVER CROPS, AND TONNAGE OF GREEN MATTER PRODUCED WHEN GROWN UNDER FIELD CONDITIONS*

| Plot | Green-manure crop | Green manure, on acre basis | Water | Nitrogen in green weight | Nitrogen per acre |
|---|---|---|---|---|---|
| | | *avg. tonnage* | *per cent* | *per cent* | *pounds* |
| 1 | Common vetch | 12.0 | 82 | 0.538 | 129.6 |
| 3 | Bur clover | 12.7 | 84 | 0.637 | 161.3 |
| 5 | Purple vetch | 20.0 | 81 | 0.569 | 228.0 |
| 9 | Canada peas | 7.5 | 80 | 0.633 | 95.2 |
| 11 | Tangier peas | 13.7 | 86 | 0.494 | 135.6 |
| 13 | Melilotus | 13.7 | 80 | 0.556 | 152.0 |
| 15 | Fenugreek | 12.3 | 82 | 0.557 | 136.5 |
| 17 | Lentils | 12.1 | 75 | 0.650 | 157.3 |
| | Average of eight legume plots | 13.0 | 81 | 0.579 | 149.4 |

* From table II of Mertz (1918, p. 10).

fixation may in reality be considered of secondary importance. In California, inorganic nitrogen can be applied to the soil and economically converted into organic nitrogen by the cover crops, provided a good tonnage can be grown in the winter season when the trees are nearly dormant.

The tonnages of several winter cover crops, produced under field conditions rather than in an orchard, as reported by Mertz (1918, p. 10), are shown in table 35. The more or less vacant spaces in the tree rows, the effect of the shade of the trees, the competition of such weeds as nettles and chickweed, reduce materially the actual yields obtainable under orchard conditions. In order to arrive at a reasonable expectation under citrus-orchard conditions, the yields shown in table 35 should be reduced at least 30 per cent for young orchards eight to fifteen years old, and as much as 50 per cent, or more, for orchards fifteen years old and older.

*Competition by weeds.*—In many sections of California it is difficult to obtain a satisfactory stand of leguminous cover crops in old orchards. The shade of the trees and the competition by shade-enduring weeds sometimes reduce the cover-crop stand to a practical failure. This trouble is most apparent on soils which have been heavily fertilized with stable manure and which may therefore naturally produce an abundance of such weeds as malva (*Malva*

*parviflora*), lamb's-quarters (*Chenopodium album*), mustard (various species of *Brassica*), prickly lettuce (*Lactuca scariola*), purslane (*Portulaca oleracea*), common chickweed (*Stellaria media*), and tumbling mustard (*Sisymbrium altissimum*). Because the ultimate cover crop may in large part become weeds, attention has been turned recently to the planting of quick-growing crops other than legumes.

Many commercial citrus growers take the view that it is better to make sure of a heavy tonnage of a nonlegume than to be confronted with a relatively light crop of legumes plus prevailing weeds such as chickweed and nettles, making a light total tonnage. This view has much in its favor, in consideration of the relatively low price of inorganic nitrogenous fertilizers and the doubtful

TABLE 36

MOISTURE AND NITROGEN CONTENT OF NONLEGUME CROPS OCCASIONALLY USED AS COVER CROPS*

| Green-manure crop | Water | Nitrogen in green weight |
|---|---|---|
| | *per cent* | *per cent* |
| Malva (*Malva parviflora*) | 79 | 0.62 |
| White mustard (*Brassica alba*) | 89 | 0.46 |
| Pigweed (*Amaranthus hybridus*) | 83 | 0.50 |

* Analysis supplied by courtesy of the Leffingwell Co., Whittier, California.

value of legumes as a means of fixing nitrogen in a soil already rich in nitrates. Such crops as malva or the various species of mustard usually compete so successfully with the above-named weeds as practically to choke them out. A good tonnage of malva or mustard can be produced in about three months, whereas a comparable tonnage of clover or vetch takes much longer. In the winter of 1927–28, white mustard (*Brassica alba*) planted in a lemon orchard on November 1 had produced a good tonnage by the middle of January.

During the fall and early winter of 1929, for comparison, purple vetch and two species of mustard were grown as cover crops in an orange orchard on property of the California Citrus Experiment Station. Figures 134, 135, and 136 illustrate the relative amounts of growth made by the three crops from September 12 to December 24. This grove has never been well fertilized; yet at the end of the 104-day period the white mustard (*Brassica alba*) was in bloom and had produced a very heavy tonnage. The Trieste mustard (*B. juncea*) made nearly as much tonnage and had the added advantage of being somewhat more resistant to cold than the white mustard. The purple vetch, on the other hand, was only one-half to three-fifths mature, with less than half the tonnage of the mustards. All the crops were infested with moderate amounts of volunteer malva plants.

Both mustard and malva are relatively rich in nitrogen while green, and disintegrate rapidly after being turned under. These crops having a high nitrogen content are much more desirable as nonlegume cover crops than the various cereals. Table 36 shows the analysis of three nonlegume plants occa-

Fig. 134. Purple vetch (*Vicia atropurpurea*) cover crop. Planted September 12, 1929; photographed December 24, 1929. Compare with figures 135 and 136.

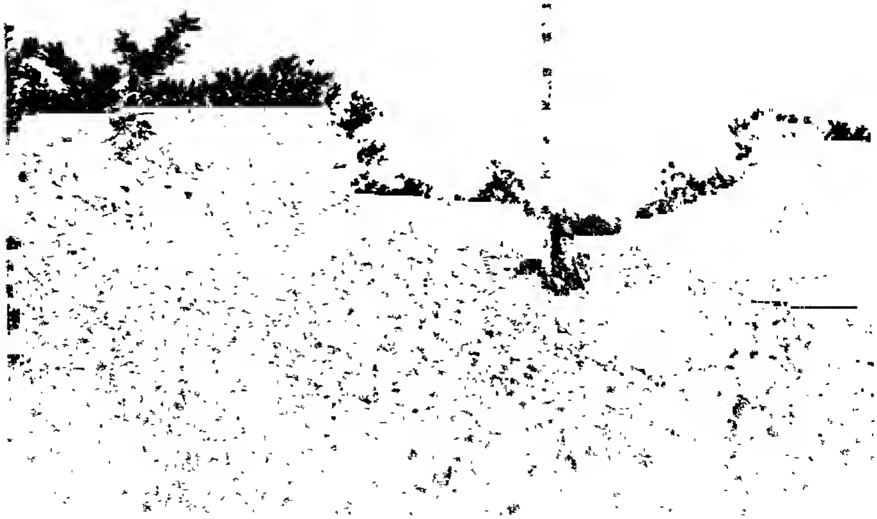

Fig. 135. White mustard (*Brassica alba*) cover crop. Planted September 12, 1929; photographed December 24, 1929. Compare with figures 134 and 136.

sionally used as cover crops. The data presented are comparable to those of table 35. Cereals will produce a good tonnage of organic matter as winter cover crops, but their slow decomposition makes their use objectionable, so that it is doubtful if they should be used generally in citrus orchards.

There is no one best cover crop for all the conditions under which citrus trees are grown. Legume crops such as annual yellow sweet clover (*Melilotus indica*) and purple vetch (*Vicia atropurpurea*) may be most desirable as winter cover crops for planting in young orchards that have not already been fer-

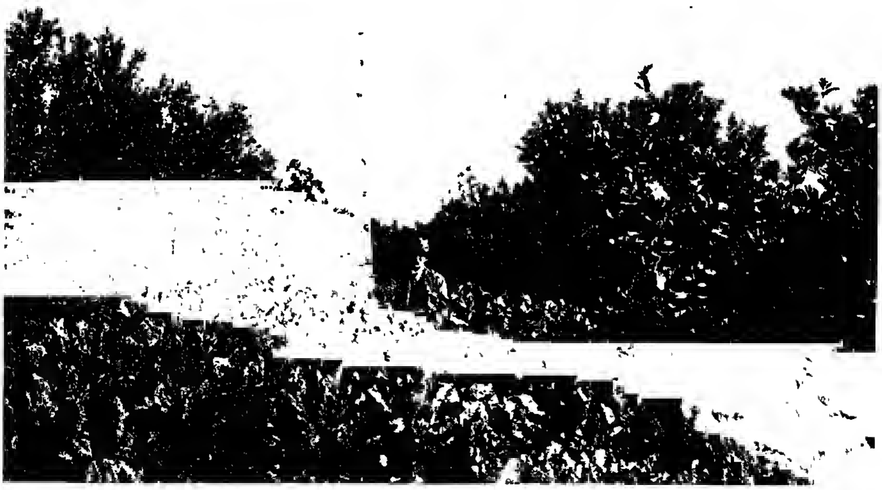

Fig. 136. Trieste mustard (*Brassica juncea*) cover crop. Planted September 12, 1929; photographed December 24, 1929. Compare with figures 134 and 135.

tilized with nitrogenous fertilizers. This would be advisable because of the nitrogen that would probably be fixed by the plant and bacteria in symbiosis. The sunny exposure in young orchards is conducive to a good growth of such winter cover crops as vetch, clover, or broad bean. Figure 137 shows a growth of purple vetch in a young lemon orchard. The crop was sown in September, 1929, and photographed in February, 1930.

On the other hand, in a bearing citrus orchard in which liberal applications of nitrogen have been made, we are not dealing in any sense with an impoverished soil, and the fixation of nitrogen may not be an important consideration. Such soils have become rich in nitrogen, and the nitrate nitrogen may vary from 5 to 20 parts per million of the dry soil when a winter cover crop is planted. Various weeds usually grow rapidly in such orchards and compete successfully with a sown cover crop. In orchards ten to twenty years old, where a large part of the land is shaded during the winter months, some nonlegume may have to be used. If the trees are planted far apart, however, it will be possible to grow a legume cover crop, as shown by the heavy winter crop of sweet clover illustrated in figure 138.

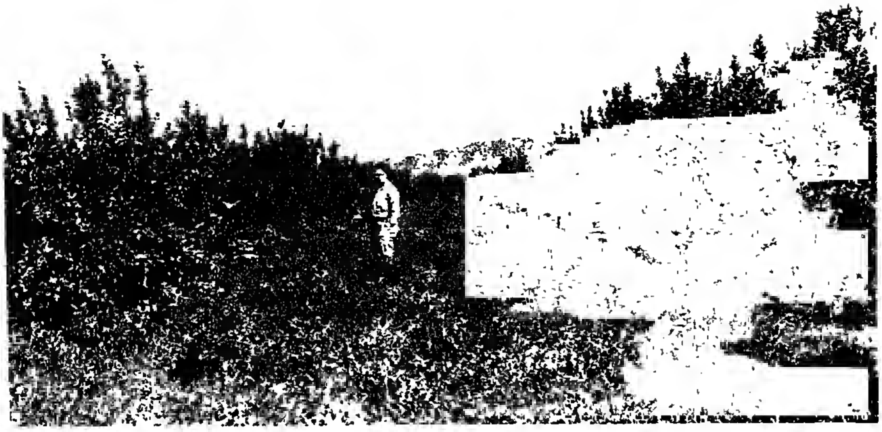

Fig. 137. Purple vetch (*Vicia atropurpurea*) cover crop. Planted in September, 1929; photographed February 17, 1930.

Fig. 138. A heavy winter cover crop of annual yellow sweet clover (*Melilotus indica*) ready to plow under before March first.

The summer legume cover crops most commonly grown with success in citrus orchards are the following: Crotalaria (*Crotalaria striata* and *C. spectabilis*), Colorado River hemp (*Sesbania macrocarpa*), velvet bean (*Mucuna utilis*), and cowpeas (*Vigna unguiculata*), illustrated in figure 139. Among the nonlegumes, pigweed (*Amaranthus hybridus*), illustrated in figure 140, has been used rather extensively in California as a planted or more commonly as a volunteer crop, and Natal grass (*Tricholaena rosea*) has been reported upon favorably in Florida.

In districts where the irrigation supply is ample, or in humid citrus sections, the summer cover crop has ordinarily given good results. Spring and summer cover crops usually compete severely with the trees for both moisture and nutrients, however, during the period when the trees are actively growing, the spring cover crop being probably worse in this regard than the summer crop. A winter cover crop, on the other hand, grows when the citrus trees are nearly dormant and is thus practically noncompetitive.

It is a common observation that attempts to grow legume crops, especially clovers or vetch, in full-bearing, thrifty citrus orchards, are invariably partial if not complete failures. In such orchards there are the alternatives of, first, allowing the various native weeds to grow as a cover crop, or, second, planting something that will compete successfully with, or choke out, the weeds. If the second method is followed, a larger tonnage of organic matter will usually be grown, unless the native weeds by chance include a large proportion of malva and the various wild mustards. Such native weeds as chickweed and nettles may completely choke out a crop of vetch or clover without making a heavy tonnage of organic matter themselves. So far as we know at present, there is no winter legume crop that satisfies this requirement of making so rapid a growth as to compete successfully with a dense infestation of chickweed or nettles. Possibly the small-seeded broad bean (*Vicia Faba* var. *minor*) most nearly meets the requirement. This crop has other disadvantages, however, such as the high cost of the seed and, especially, the injury the plants suffer in the grove as the result of the tramping and trucking necessary for picking fruit and serving orchard heaters. For these reasons it has not become a common cover crop. In Valencia orange orchards, however, where it is not necessary to pick any of the fruit during the winter, and where the orchards are so situated that orchard heating is not necessary, the small-seeded broad bean makes satisfactory growth.

The impracticability of using legumes as winter cover crops in mature citrus orchards has caused many growers to turn to such crops as the various mustards, malva, and rape. These three crops contain relatively large percentages of nitrogen, and, if turned under before reaching full maturity, will quickly decompose. All these plants, especially the mustards, make a rapid growth when sown in the fall. When mustard competes with nettles or chickweed, the mustard usually makes up the greater part of the final green tonnage. It is for this reason, and because mustard may be planted at the beginning of the rainy season, which in California may be as late as the early part of November, that it is frequently used as a cover crop in citrus orchards.

Fig. 139. Cowpeas (*Vigna unguiculata*) grown as a summer cover crop in a young orange orchard.

Fig. 140. A summer cover crop of pigweed (*Amaranthus hybridus*). Photographed three and one-half months after seeding.

By fertilizing the orchard with the cheapest sources of inorganic fertilizers possible, plus the growth of these vigorous nonlegumes, the citrus grower may be further ahead in the end than by growing a medium or poor legume crop with only a small tonnage of organic matter, even though more nitrogen might be added to the soil by the latter method. It is well to repeat, however, that in young orchards where the weeds have not become thoroughly established some legume cover crop can be used profitably, and is probably more desirable than any nonlegume crop. Melilotus clover, purple vetch, or broad beans are preferred for legume winter cover crops in California.

Sometimes, greater yields of field crops have followed nonleguminous than leguminous green-manure crops. For example, in Virginia the yields of certain crops following corn and sorghum and the natural vegetation were larger than those that followed cowpeas and soy beans. According to Johnson (Pieters and McKee, 1929, p. 992), the natural vegetation consisted of a heavy growth of crab grass with common weeds. Hall (1910, p. 274) reports that at the Woburn Experiment Station, England, after several trials, crops that followed mustard were always better than those that followed vetches, despite the fact that the vetches had contributed a greater weight, both of dry matter and of nitrogen, to the land. In this connection, Pieters and McKee (1929, p. 987) state that in Alabama a relatively small crop of vetch has given better returns on cotton than a heavy crop. They suggest that some crops may not be able to utilize advantageously the large masses of green matter turned under, and that smaller amounts may often serve quite as well.

## CULTURE AND DISPOSAL OF COVER CROPS

*Winter cover crops.*—In view of the general belief, in California, that it is desirable to turn under the cover crop in a citrus orchard in the late winter or very early spring, the crop should be planted relatively early so that it will make a satisfactory tonnage by that time. Five months' time is required to make a fair production with legume cover crops. Hence, if such a crop is to be turned under by February 15, it must be planted not later than September 15.

Mustard or malva, on the other hand, will make a fair tonnage in three months and can be planted in the warmer citrus districts as late as November 1 and still make a good crop by February 1. In fact, it may be desirable to postpone the planting of a mustard cover crop until October 15 to November 1. If planted much before then, the mustard is likely to be in full bloom by the end of December. This is an undesirable time to incorporate the cover crop into the soil, especially in orchards so situated that one of the reasons for the cover-cropping practice is the drying out of the soil moisture on land which is naturally too cold and wet during the late winter. This is also too early, in the California districts, to turn under a cover crop on hillside land, where one of the advantages of a cover crop is prevention of erosion. The alternative of allowing the early-planted mustard to continue to grow until February is a disadvantage, inasmuch as the full maturity of the crop to a tough, fibrous condition is not desirable because of the slow rate of disintegration of such material, as previously pointed out. In orchard heating, the presence of a tall

cover crop is a hindrance. With mustard waist-high from the middle of December to the end of the winter, orchard heating becomes a difficult and especially unpleasant task. For these several reasons, mustard may be a more satisfactory crop if planted from October 15 to November 1 than if planted earlier. In orchards where soil erosion is an important consideration, the planting of a cover crop at an early date is probably justified. In such orchards, sowings somewhat earlier than heretofore noted may be essential. If the early-sown mustard cover crops are in the way of orchard-heating operations, they can be mowed just before blooming; a secondary growth will be made later in the season.

If the practical considerations in turning under a winter cover crop in a citrus orchard can be made to harmonize with the principles governing most effective use of such crops, good effects on the citrus are likely to follow. Just before such cover crops as melilotus clover or vetch reach the blossoming stage, they have produced about 80 per cent of their ultimate tonnage. They are still quite green and succulent, and at the same time have closely approached, but not fully attained, the maximum total nitrogen. This stage in the growth of the cover crop may be considered one of the most favorable at which to turn it under. Postponement of tillage for the added tonnage and total nitrogen that might be obtained by allowing the crop to mature does not seem justified in view of the resultant slower decomposition of the crop. Winter cover crops should be, and usually are, turned under a month or six weeks before the blooming of the orange trees. The rapid decomposition of the cover crop is essential to the successful use of this method of culture. Casual observations indicate that the incorporation of a winter cover crop into the soil at full maturity, in a dry, fibrous condition, has often done more harm than good.

*Summer cover crops.*—Much that has been said of winter cover crops is also applicable to summer cover crops, with merely a change in the seasonal considerations. In regions of heavy summer rains, such as Florida, the use of summer cover crops is by all means the most favorable method of producing organic matter as a supplement to fertilization. Also in regions where there is an abundance of cheap irrigation water, as in the desert regions of California and in certain places in Arizona, the growth of summer cover crops becomes entirely practicable. Any one of the several warm-season crops can be planted as soon in the spring as the ground is warm enough to induce good germination and growth.

The use of summer cover crops as a means of reducing the intake of nitrogen by grapefruit trees during the late summer and fall has been beneficial in one respect in Arizona (Martin, 1940): the trees thus treated have produced a higher proportion of smooth, thin-skinned fruit of high commercial quality than comparable trees growing in plots not summer cover cropped. The growth of weeds, or at least the lack of cultivation, has been shown to be conducive to the production of fruit of good quality in Florida (Lenfest, 1924). On the other hand, in much of the coastal region in California it is entirely impracticable to grow a summer cover crop, because a limited supply of irrigation water must be conserved during this rainless period.

*Amount of seed to sow.*—The amount of seed to sow per acre depends somewhat upon such factors as the quality of the seed, the season, and the age of the orchard. If seed is sown at a rather unfavorable season of the year, or at a time that is unfavorable with respect to the irrigation interval, it may be advisable to use a greater amount than would otherwise be required. A young orchard in which nearly all the ground is seeded will obviously take more seed than an older orchard in which, at the most, only two-thirds of the land is planted. The seedage shown in table 37 is recommended for young orchards

TABLE 37

AMOUNT OF SEED OF THE VARIOUS COVER CROPS TO SOW PER ACRE*

| Crop | Pounds per acre |
|---|---|
| Annual yellow sweet clover (*Melilotus indica*) | 25 |
| Canada field pea (*Pisum arvense*) | 90 |
| Colorado River hemp (*Sesbania macrocarpa*) | 25 |
| Common vetch (*Vicia sativa*) | 80 |
| Cowpea (*Vigna unguiculata*) | 60-120 |
| Crotalaria (*Crotalaria striata*) | 8 |
| Egyptian clover (*Trifolium alexandrinum*) | 15 |
| Natal grass (*Tricholaena rosea*) | 6 |
| Purple vetch (*Vicia atropurpurea*) | 80 |
| Rape (*Brassica Napus*) | 6 |
| Small-seeded broad bean (*Vicia Faba* var. *minor*) | 25 |
| Tangier pea (*Lathyrus tingitanus*) | 60 |
| Trieste mustard (*Brassica juncea*) | 5 |
| Velvet bean (*Mucuna utilis*) | 30 |
| White mustard (*Brassica alba*) | 6 |

* For young orchards in which nearly all the land is planted to cover crop. Less seed is required per acre in older orchards, and modifications should be made accordingly.

in which nearly 100 per cent of the land is planted to cover crops. Modifications can be made as conditions warrant.

*Methods of sowing.*—The preparation of a good seedbed is as important in sowing a cover crop as in growing any field or garden crop. With small-seeded crops such as the clovers, mustard, or rape, the seed may be sown on the well-prepared soil after the irrigation furrows are made. In actual practice, under orchard conditions, this will mean merely sowing it on the dry soil just before irrigation. If the irrigation water is then run in the furrows for a sufficient length of time to wet the surface soil thoroughly, the small seeds will settle in among the small lumps of wet soil and will have germinated before the soil can dry out. Good cover-crop stands are thus obtained without harrowing the seed into the soil. Where the soil is sandy, or where the lateral movement of irrigation water on the surface soil is limited, it may be advisable to harrow the land lightly immediately after seeding and before furrowing.

For the larger-seeded crops such as the vetches or peas, it is advisable to cultivate the land to a depth of two to three inches to cover the seed. This may be done by a disk harrow set very shallow or equipped with rollers to prevent deep penetration. After this operation, the land should be furrowed out. The land may then be irrigated if the seed is sown during a dry period.

It is not commonly practicable to depend upon the rains to start the growth of the cover crop in arid sections. Care should be taken, however, not to use an excessive amount of water in starting cover-crop growth. Citrus trees may be injured by the application of much more water than is actually needed for tree growth.

*Moisture requirements.*—If a cover crop is grown in a citrus orchard in a semiarid region, it will be necessary to apply some irrigation water in addition to that which would be necessary if clean culture were maintained. The actual amount of extra water made necessary by winter cover cropping in the various citrus districts of the arid or semiarid regions will vary greatly. The factors which influence this are rainfall, humidity, temperature, soil types, and the particular cover crop grown. The average annual rainfall in the several citrus-growing districts in California, for example, varies from 3 inches to 24 inches. The extremes of annual rainfall occurring in these districts have varied from 0.64 inch to 47 inches. Obviously, under such widely varying conditions no definite amount of water can be recommended for application to a cover crop. The average annual rainfall of 20.64 inches in the Upland, California, district may be expected to produce a good winter cover crop without extra irrigation water if the rains are favorably distributed. The rainfall in El Centro, California, however, may average only 3 inches, and the winter cover crop is thus almost solely dependent upon irrigation water.

The average use of water in the citrus districts of southern California varies from 12 to 36 acre-inches or more per acre per year. A cover crop of 10 tons per acre may require 12 inches or more of water per acre to produce the crop. The probable amount of extra water necessary to grow a winter cover crop, over and above the normal water supply of the land, must be calculated with a knowledge of the probable rainfall, the soil type, and the usual amount of water required for each district. This extra water will vary all the way from none in some districts to 18 inches in others.

To meet the needs of the cover crop, light but frequent irrigations are best. Under many irrigation systems, however, it may be impossible to obtain water more often than every thirty days, especially during the early fall. In the interior valleys of California it may therefore be advisable to wait until the latter part of September or early October before planting, in order to avoid losing the crop from the excessive heat that often occurs in these sections in early September. For such late planting the vetches or the mustards are usually more successful than melilotus clover.

The distance between the irrigation furrows is important in preparing the land for a cover crop. On sandy soils the furrows should be only 18 to 30 inches apart. On clay loams, or on soils underlain with a hardpan, the distance between furrows may be greater and still permit the entire surface to become wet when the land is irrigated. It is also desirable to make relatively shallow furrows, so that the entire surface of the soil will become wet, the water moving by capillary action from the furrows to the interspaces. This is essential if the cover crop is to be produced uniformly over the entire area of the soil.

*Disposal of cover crop.*—The decay of a cover crop in an orchard soil is essential to its beneficial use. To promote decomposition, it is necessary that the material be incorporated with damp soil. It might be considered advisable, therefore, to turn under a cover crop to a depth somewhat in excess of that provided by the shallow summer cultivation. Care should be exercised in this operation, however, to make sure that plowing or disking is not so deep as to cut many roots of the citrus trees. All orchard disks should have rollers on them to prevent excessively deep penetration in mellow soils (see chap. vi and fig. 118). It may sometimes be desirable to break down a large cover crop with a drag or disk before working the crop into the soil. This procedure makes plowing or final disking easier, and lessens the loss of water by transpiration—a result to be desired if the soil is drying out more rapidly than the cover crop can be turned under.

If a winter cover crop has been planted early in the fall, it should be ready to turn under between the first and the middle of February, when several rainstorms may be expected after the plowing. This is thought desirable for the purpose of promoting the decomposition of the cover crop as well as the downward movement of the fertilizer materials that may be applied just prior to plowing or disking, and also the movement of the soluble materials resulting from the decomposition of the cover crop.

## RELATION BETWEEN COVER CROPS AND FROST DAMAGE TO CITRUS TREES

In recent years there has been an increasing prejudice against the use of cover crops, because of the popular belief that the minimum temperature is lower, and hence the frost damage to citrus trees greater, in a cover-cropped area than in a clean-culture area.

This problem has been the subject of a series of investigations by Young (1925, p. 390), who concludes that cover crops do increase the frost hazard, but only slightly. He compares minimum temperatures in two adjacent and comparable areas over a period of 24 nights in January. At a 5-foot elevation the unsheltered thermometers showed the cover-cropped plot to be colder than the clean-culture plot 18 nights out of 24, the difference between the plots ranging from –0.1° to –1.3° F. Four nights out of the 24 the cover-cropped plot was the warmer, with a range in the difference of from +0.1° to +0.3° F. On two nights there was no difference in the temperatures of the two plots. The average difference of –0.4° F. for the entire period indicates a high probability that a cover-cropped area will be colder during the night than a comparable clean-culture area, although the differences in temperatures may be relatively small. If an orchard is already equipped with orchard heaters, the relation of a cover crop to frost hazard need not be given serious consideration.

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# Chapter IX

# PRINCIPLES AND METHODS OF PRUNING

BY

ROBERT W. HODGSON

Of all the orchard-management operations employed by citrus growers the one least agreed upon is pruning. Current practice varies from no treatment whatever to regular annual pruning, often severe. At present the tendency in California is toward greater regularity and much less severity of pruning. To many a citrus grower, nevertheless, pruning is still a mechanical operation, assumed to be important in some degree, and practiced in a more or less desultory fashion according to whatever system may happen to be currently in favor in his locality.

## GENERAL CONSIDERATIONS

*Definition.*—In this discussion, pruning will be considered to include the removal of all vegetative parts, dead or alive, from the time when the tree is headed in the nursery row throughout its life in the orchard.

*Function and objects.*—In general, the function of pruning is to regulate the growth of the plant by determining the location, kind, and number of the shoots. The specific regulations of growth desired by the citrus pruner may and do vary greatly and will be discussed in some detail later. They should represent definite objectives.

There is general agreement that the two primary objects of pruning citrus trees are (1) the establishment of a strong and well-balanced framework system and (2) the maintenance of that balance between vegetative vigor and fruitfulness which is conducive to the economical production of maximum crops of the best quality and is at the same time consistent with the maintenance of tree health.

*Importance.*—The achievement of the first objective obviously necessitates some pruning, although, as will be shown later, citrus usually needs less than many other fruits. In the attainment of the second objective, however, pruning is but one, and in all probability the least in importance, of the various orchard-management operations. In many citrus-producing regions, properly cared-for trees that are on good soils and are protected against injury from external agencies can be maintained in good vigor and production for many years with little or no pruning; in California and Florida, at least, there are sufficient numbers of old, unpruned, yet high-yielding orchards to establish the fact.

*The place of pruning in orchard management.*—It cannot justifiably be argued that pruning, even the training of young trees, is essential to the production of citrus fruits. Neither has it been established that under favorable conditions of environment pruning is of great importance or benefit. By far the greater part of the orchards, however, have at some time suffered from neglect or injury, and pruning is often a help to promoting their recovery.

Pruning should be looked on, therefore, as merely one of a number of operations, ordinarily to be avoided but occasionally helpful, which may be employed in the regulation of the nutritional balance in the trees, but which, if employed at all, should be used sparingly and with discretion.

## SPECIAL APPLICATIONS TO CITRUS

Including the two general objects already mentioned, the principal reasons for pruning citrus trees may, for convenience in discussion, be grouped under several headings (appropriate methods are described in a later section).

*Form.*—The training of young citrus trees to a desired form is concerned, first, with height of head and method of establishing it, and second, with development of a strong and properly balanced system of framework branches.

In the early days of the citrus industry in both Florida and California it was customary to establish the heads of the trees high—at 4 or 5 feet, or even higher. This appears to be the natural growth habit of seedling trees in general, and of some of the more vigorous varieties. Aside from making easier the cultivation done near the trunks of the trees, which is relatively unimportant, there appears to have been little in favor of this system of heading, and in California and Florida at least it was long ago abandoned. The impelling cause for its abandonment in Florida was the disastrous freezes of the seasons of 1894–95 and 1899, which killed many thousands of trees down to the roots and demonstrated conclusively that, in that state, the most effective means of protecting young trees against freeze injury was to head them low, 12 to 18 inches from the ground, and to mound or bank up soil about the trunks and heads—a practice which has persisted ever since. In California, however, medium heading, at heights of 24 to 32 inches, gradually supplanted the older practice of high heading, and for many years has been the system universally used.

The advantages of medium or low heading over high heading are numerous and well justified. Under the old system of high heading the trees were unnecessarily tall, with the obvious disadvantage of expensive costs of spraying, fumigation, and picking of the fruit. The lower-headed trees not only are more desirable as avoiding that disadvantage, but also benefit from greater natural protection of the trunks against frost and sunburn. The inconvenience to soil-management operations which is often mentioned as an objection to the low- or medium-headed tree is easily overcome by the use of implements provided with extensions and shields, the latter to protect the low-hanging fruit against bruising. Growers can well afford to lose the small amount of fruit which bruising from tools or rubbing on the ground may render unsalable, for the much larger amount of high-quality fruit which citrus trees characteristically produce on the lower branches.

Training as a means of establishing a strong and well-balanced framework is especially important with the lemon and vigorous, upright-growing orange varieties. The grapefruit, navel orange, and other varieties of semidrooping habit of growth will ordinarily develop, without assistance, relatively satisfactory systems of framework branches, and hence usually require a minimum of training treatment.

*Physical condition.*—With bearing lemon trees a certain amount of pruning is required for the maintenance of a system of framework limbs that is compact enough to prevent breakage when the heavily laden branches are swayed by wind, as well as to minimize rubbing and scratching of the fruit. Although the unpruned lemon tree during its early bearing life will grow larger and bear more fruit than the pruned tree, the spreading habit of growth, together with the weight of terminal fruit borne by the unpruned tree, renders it much more subject to breakage and fruit injury than the tree pruned to a more compact form which resists better the swaying action of the wind. Moreover, experience indicates that, although smaller in quantity, the fruit on the pruned tree usually attains picking size earlier and is of better grade, and hence brings a higher total return, than that from the unpruned tree. Furthermore, the properly pruned tree requires less propping and bracing than the unpruned one.

Certain orchard-management costs, including those for spraying, fumigation, and picking, bear a direct relation to the size of the tree, especially its height; the taller the tree, the greater are these costs. Hence, under certain conditions there is a size and height, appreciably affected by economic factors, beyond which it is unprofitable to permit the trees to grow. Obviously this varies greatly in different regions and localities and with the several citrus fruits; with some of them, under favorable conditions, it does not exist at all. With the lemon, however, this factor is often important, especially in relation to costs of picking, which are always much higher than for any of the other citrus fruits. It is not surprising, therefore, to find that many lemon growers consider it inadvisable and unprofitable to permit their trees to attain heights greater than 12 to 15 feet, which are much less than those normally reached by unpruned trees growing on fertile soils. (See fig. 141.) This is undoubtedly the sole reason for the widespread practice of pruning this tree to a relatively low, broad, and nearly flat form which facilitates harvesting the crops; also the chief reason, in certain of the Italian lemon districts, for pruning the trees to semidwarf size.

In arid subtropical regions in general, all citrus varieties exhibit a tendency to compactness of fruit-wood growth and density of foliage, as a result of which the interior parts receive little or no sunlight and the fruit-bearing shoots in the interior and under parts of the tree decline in vigor and ultimately die, with the result that the crop is produced entirely in the outer "shell" of fruit wood. Much of this fruit is "outside" fruit and during its growth and maturity is directly exposed to the weather. Numerous counts have shown that, with navel varieties in particular, it is the outside fruit which suffers most from splitting, from large, open, and protruding navels, and from blemishes lowering the quality. On the other hand, the "inside" fruit is invariably smoother in texture and of better average grade. It has been demonstrated that by pruning which permits the entrance of light in moderate amounts the presence of healthy interior fruit wood can be maintained more or less indefinitely, making possible the production of crops of better average quality.

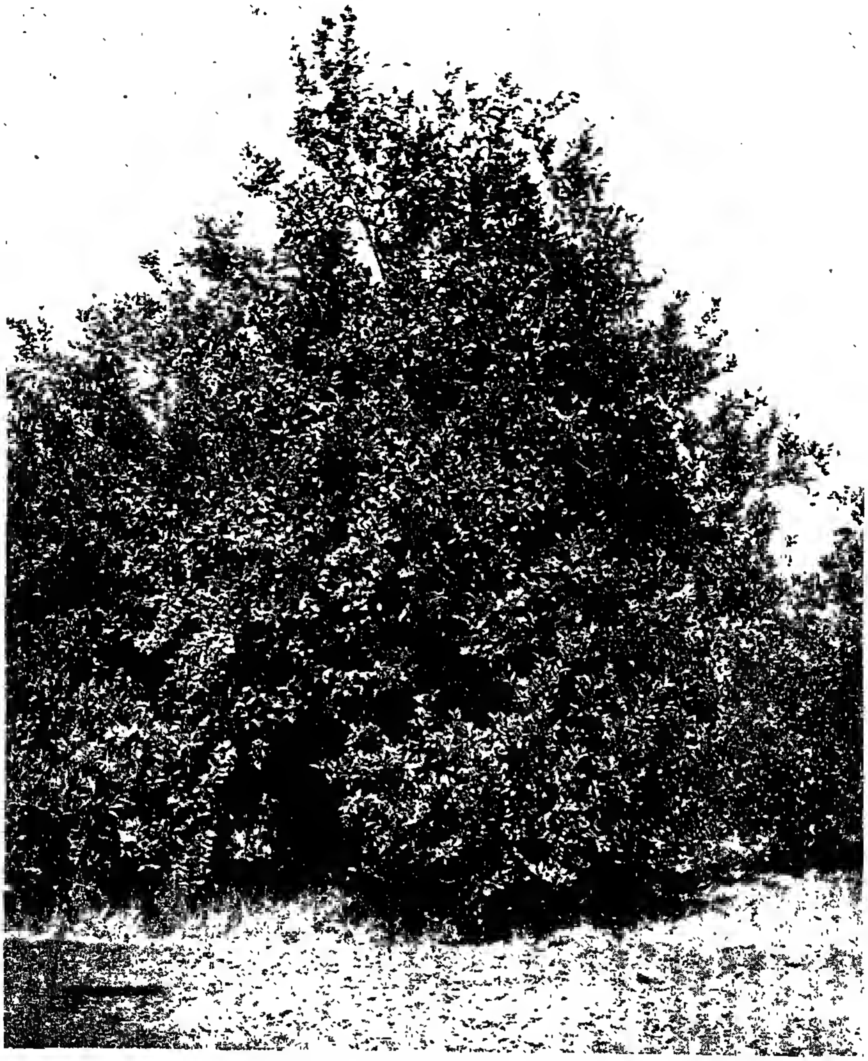

Fig. 141. Large, full-bearing unpruned lemon tree, more than twenty feet in height. Costs of fumigation, spraying, and harvesting are excessive. Pruning is of greater importance with the lemon than with most of the other citrus fruits.

*Balance between tree growth and fruiting tendencies.*—The balance between vegetative growth and fruitfulness which the citrus grower desires is obviously that fruitfulness shall be maintained and that trees shall nevertheless continue to make a moderate amount of growth. Growth is normally great-

est when the trees are young, but thereafter gradually declines until, when the trees are old, it may be necessary to prune them to cause new growth. Pruning for this purpose is often unnecessary, however, and often overdone.

As the trees age, a gradual renewal of the fruit-bearing wood may be brought about by removing the older and weaker parts. The lower and under parts are ordinarily the first to lose their usefulness, primarily from crowding out and shading by the higher, newer, and more vigorous parts. Eventually, then, the lower branches should gradually be removed, and if this is regularly and properly done it tends to maintain a desirable physiological balance in the trees.

*Facilitation of orchard operations.*—Some pruning may be necessary as an assistance to other orchard-management operations. It must be admitted, however, that the assumed necessity is sometimes more fancied than real, as when the trees are pruned up from the ground in order to make cultivation and irrigation easier. The removal of lower branches, necessitated by their decline, will ordinarily keep the trees pruned high enough to permit easy cultivation underneath.

Control of the melanose disease in Florida is practicable only when, by means of pruning, the trees are kept clear of dead and dying fruit wood. In California, control of brown-rot disease of the lemon is materially assisted by pruning the trees so that the lowest branches hang a foot or so above the ground; this not only reduces the proportion of infected fruit, but also greatly facilitates spraying the ground under the trees as well as the lower-hanging branches and fruit.

## RELATIVE IMPORTANCE OF PRUNING IN THE DIFFERENT CITRUS-PRODUCING REGIONS

In none of the citrus-producing regions can pruning properly be regarded as requisite to success, though doubtless in many it may often be employed with advantage. In general, pruning may be of greater economic importance where labor costs are high than where they are low, and of greater cultural importance in arid subtropical regions than in humid subtropical or tropical regions. Perhaps the greatest contrast occurs in orange and grapefruit pruning in Florida and in California. In Florida, virtually the only pruning justified is the removal of dead wood for successful control of the melanose disease. In California, a moderate amount of opening up to encourage interior fruiting, together with some attention to renewal of the fruit-bearing wood, is undoubtedly desirable and beneficial. In Florida, costs are low; in California they are high. And the growth habits of the trees differ materially in the two states.

Of all the citrus fruits, the grapefruit seems to benefit least from pruning. Next is the orange, some varieties of which, however, notably the Washington Navel, respond favorably to a moderate amount of pruning. The lemon and citron appear, under all conditions, to require and benefit from more pruning than any of the other citrus fruits.

## SOME FACTORS RELATING TO THE CITRUS PRUNING PROBLEM

### THE NATURAL HABIT OF GROWTH

It is the nature of most of the commercially important citrus trees to grow upright—a tendency which, unless it is curbed by pruning, results in the production of tall, more or less columnar, trees. The major exceptions to this rule are the citron, some of the limes, and the Satsuma and Mediterranean mandarins, none of which, except the citron, appears especially to require pruning. It should be noted, however, that the tendency to uprightness is more marked in some citrus trees than in others, and is more pronounced in certain varieties than in others. Moreover, it varies greatly under different environmental conditions.

The uprightness that is characteristic of the citrus tree is most pronounced in the branches; dominance of their terminal growing portion is commonly very marked (Reed and Halma, 1919). As long as the branch remains in an upright position, the dominance persists and the production of lateral shoots is either scanty or lacking. If, however, the branch assumes or is forced to take a horizontal position, terminal dominance ceases and the upper lateral buds are released into growth, with consequent development of lateral shoots (Halma, 1923) (fig. 142). Usually, one of the upright lateral shoots grows more vigorously than the others and becomes the dominant branch. It may grow so vigorously as not only to check the growth of the other laterals, which then normally become fruiting shoots and assume a horizontal position, but also to dwarf markedly the growth of that part of the parent shoot which is farthest from its point of origin, and thus to accomplish a natural pruning of the mother branch at that point (fig. 143). What eventually causes a dominant upright branch to assume a horizontal position and yield its dominance to a daughter shoot is the weight of fruit and leaves produced on the smaller laterals which it originally dominated, and of the fruit they produce terminally if exposed to light. When the horizontal position is reached, again a daughter shoot assumes the dominance; and the cycle is repeated. This is the natural sequence of events in the growth of citrus trees—a constant renewal of growth from above, with consequent forcing downward and dwarfing of the older growth. The inevitable result of this natural habit is that as the trees age the older and lower parts decline, not only from the dwarfing influence already noted but also from the shading effect. Thus the lower part of the trees gradually fill up with weak and declining wood until the density becomes so great that pruning must be resorted to. And eventually, for reasons already noted, it becomes necessary to remove the worn-out lower branches. It is this growth habit that has given rise to the general principle of "undercutting" in citrus pruning.

The vigor of growth of the upright shoots, as well as their occurrence, varies greatly with the several varieties and under different climatic conditions. Moreover, it is influenced materially by the age and vigor of the tree and by

their relative position in the tree. Under given conditions, they are apparently most vigorous in the lemon, and, next in order, in the Valencia orange, the navel orange, and the grapefruit. Perhaps the greatest differences in this respect, however, relate to climatic conditions. In regions of wide seasonal and

**Fig. 142.** Lateral branch development on a vigorous orange shoot held in the horizontal position inside a young tree. The absence of light in the proximal portion of the branch has resulted in the growth of vigorous upright vegetative shoots, known popularly as "riders."

daily ranges in temperature, such as occur in the great interior valley and desert areas of California, the vigor of these shoots is most pronounced, much more so than in regions of more equable climate; and in young trees especially, their rapid growth, usually to a distance of several feet, and the unshapely form resulting therefrom, often perplex the growers, some of whom are inclined to remove them by pruning. Although, as will be shown later, there may be occasion to remove some of them, no greater mistake can be made than to

keep the trees free from them entirely. Under the conditions described, this is the natural way in which the trees increase in size.

Moreover, the vigor of growth of these shoots is more or less proportional to the age and vigor of the parent trees. They are most vigorous in young

Fig. 143. A lateral daughter orange branch ("rider") which has assumed dominancy and is dwarfing the terminal portion of the mother branch. Its weight of foliage, developed by exposure to light, is causing it to assume a horizontal position. It will be observed that the lateral shoots are on the upper side of the daughter branch.

trees, but as the growth tendency declines with age, so does the vigor of these shoots, until eventually they no longer occur unless pruning is resorted to. In general, the larger the branch on which they arise, the greater is their vigor (fig. 144). It has long been recognized that shoots of this kind, commonly known as "water sprouts," which are produced on the trunk or main branches are much more vigorous and extend much farther than those which arise on the smaller branches. The facts are that these shoots, irrespective of position, con-

Fig. 144. A vigorous vegetative shoot ("sucker") arising from below the head of the tree. Its removal while still small would have been advisable, but at the stage shown it is probably better to leave it but keep it under control, though the result may be an unshapely, lopsided tree for several years to come. If uncontrolled, it may develop a "two-story" top to the tree.

tinue to extend until they reach the sunlight, and that the vigor of the shoot is in direct proportion to the distance it must go. When sunlight is reached, however, extension stops and terminal branching ensues, the eventual result of which is the production of fruit wood and fruit. If nothing prevents, the weight of the fruit bends these branches over, the production of lateral fruit-bearing shoots then occurs, and these effectively transform the water sprout to a fruitful branch. (See fig. 143.) The maintenance of a proper light relation in the tree, often possible only by means of pruning, is a valuable means whereby such growths can be controlled and utilized.

## THE CARBOHYDRATE-NITROGEN BALANCE

In the absence of deterrent factors, the balance in the plant between growth and fruitfulness seems mainly to be some relation between carbohydrates and nitrogenous compounds. With reference to this relation all plants have been placed in four general groups (Kraus and Kraybill, 1918). Two of the groups represent conditions of disease induced by deficiency; the other two, conditions of health but of differing vegetative and fruiting tendencies.

Plants which exhibit either carbohydrate deficiency or nitrogen starvation are obviously unable to grow or fruit normally. On the other hand, plants with a plentiful nitrogen supply and high carbon assimilation are found to make a moderate amount of growth and yet bear satisfactory crops. This physiological condition, often referred to as *optimum fruitfulness*, is manifestly of interest to the fruitgrower. Plants which have plenty of nitrogen available, but which manufacture carbohydrates in moderate amounts only, are found to make vegetative growth at the expense of fruit production—a physiological condition generally referred to as *vegetative growth*. The essential difference between these two conditions appears to relate to the storage of carbohydrate reserves: if carbohydrates are sufficient in amount to provide for storage, fruit-bud differentiation occurs and the plants are fruitful; if not, vegetative growth continues.

Although it may be argued that these relations have not yet been established experimentally for citrus trees, the fact remains that the carbohydrate-nitrogen hypothesis serves to explain many of the facts observed in the behavior of citrus trees, and especially their responses to pruning. Thus, it has long been observed that newly planted trees are for the first few years vegetative, a condition which is most marked where the soil is high in fertility. As carbon assimilation increases, however, with the ever-expanding leaf surface of the rapidly growing trees, eventually a storage of reserves occurs and the physiological condition of the trees changes from that of vegetative growth to that of optimum fruitfulness. And it has long been known that when the soil fertility is exhausted, after some years of bearing, the yield and vigor of the trees decline—a condition which can usually be remedied or prevented by resorting to the use of nitrogenous fertilizers.

Again, it has been shown conclusively that pruning young trees merely delays their coming into bearing, whereas severe pruning of young bearing trees often throws them out of the bearing condition. In the one case, the vege-

tative physiological condition is accentuated; in the other, the recently attained physiological condition of optimum fruitfulness is changed to the vegetative state. Moreover, there can be little question that the "water-sprout" shoot is merely a branch in a vegetative physiological condition induced by lack of light enough to favor photosynthetic activity. On reaching the sunlight its physiological condition is changed, with the results already described.

There is therefore reason to believe that the general carbohydrate-nitrogen balance in the citrus tree is importantly related to its responses to pruning.

## SOME EFFECTS OF PRUNING ON CITRUS TREES AND SHOOTS

Certain effects, both general and specific, which result from the pruning of citrus trees and shoots in California have long been recognized by observant growers and pruners. Experimental work, however, was not undertaken until about twenty-five years ago. Within recent years data have been accumulated which demonstrate conclusively that, in general, pruning is markedly depressive to growth and fruitfulness in citrus trees, and that the diminution is approximately proportional to the severity of the treatment. This has been shown to hold for young lemon trees, young-bearing orange and lemon trees, and healthy full-bearing orange, lemon, and grapefruit trees. It is impossible to escape the general conclusion that pruning as applied to young and bearing citrus trees reduces both growth and yield and that, if practiced at all, it should be applied in moderation and with discretion. A few only of the typical results obtained will be referred to here; references are given to the results of additional experiments.

*Effects on young trees.*—The most extensive and valuable studies of the effects of pruning on young citrus trees in California are those conducted on Lisbon lemon trees by Blanchard (1930, 1932). The results obtained from only one of his experiments will be presented and discussed (1930). For this experiment there were six plots, each composed of seven trees, all remarkably alike and growing on a nearly flat piece of fertile soil near Santa Paula. At the time the experiment was started, the trees had made two season's growth and, except for a slight amount of training, had not been pruned. The first pruning was given in the early part of the third season after planting, and for six years differential pruning treatments were applied to the two sets of three plots. One set received very light treatment, consisting only of thinning and pinching. The other received for three years the standard pruning treatment formerly almost universal in California, which consisted of heading back some of the vigorous upright shoots and removing others, together with eliminating the small hanging branchlets. Beginning with the sixth season this set was pruned somewhat less. A summary of the production for the duration of the experiment is given in table 38 (p. 422).

The marked decrease in yield resulting from the more severe yet standard pruning practice is clearly shown by the difference of 6,677 pounds of lemons for the six-year period reported. The rate of decrease is slightly more than

4,000 pounds per acre per year. Moreover, from the third year on, the lightly pruned trees were distinctly larger in both volume of top and size of trunk than the standard pruned trees.

There can be little question that California citrus growers, especially lemon growers, have suffered important losses of fruit and materially delayed the growth of their trees by pruning young trees too severely. (See discussion of effects on fruit quality, p. 425.)

TABLE 38

SUMMARY OF YIELDS IN A PRUNING EXPERIMENT ON YOUNG LEMON TREES

| Plot | 1926 | 1927 | 1928 | 1929 | 1930 | 1931 | Total |
|---|---|---|---|---|---|---|---|
| **Standard pruning treatment** | | | | | | | |
| | Average yield per plot of seven trees each (pounds) | | | | | | |
| Plot 1 | 187 | 597 | 1,032 | 1,305 | 1,356 | 3,008 | 7,485 |
| Plot 2 | 255 | 623 | 1,110 | 1,349 | 1,532 | 3,115 | 7,984 |
| Plot 3 | 287 | 638 | 1,081 | 1,392 | 1,837 | 3,034 | 8,269 |
| Total | 729 | 1,858 | 3,223 | 4,046 | 4,725 | 9,157 | 23,738 |
| **Light pruning treatment** | | | | | | | |
| | Average yield per plot of seven trees each (pounds) | | | | | | |
| Plot 4 | 587 | 825 | 1,271 | 1,443 | 1,736 | 3,337 | 9,199 |
| Plot 5 | 741 | 1,014 | 1,519 | 1,719 | 2,113 | 3,930 | 11,036 |
| Plot 6 | 536 | 802 | 1,504 | 1,704 | 2,197 | 3,437 | 10,180 |
| Total | 1,864 | 2,641 | 4,294 | 4,866 | 6,046 | 10,704 | 30,415 |
| Difference | 1,135 | 783 | 1,071 | 820 | 1,321 | 1,547 | 6,677 |

*Effects on young-bearing trees.*—That the depressing effects of severe pruning persist as the trees age and come into bearing has been equally well demonstrated in the lemon-pruning experiment conducted by H. S. Reed and F. F. Halma at the Citrus Experiment Station at Riverside, California. In this experiment, pairs of plots, each of five trees, were pruned according to four widely used systems of pruning, which differed mainly in the amount of growth removed, although to some degree also in the frequency and manner of removal. Control plots on which no pruning was done were also maintained. The results resemble those cited in table 38: the yield and size of tree consistently varied in inverse relation to the severity and frequency of pruning. The unpruned trees were the largest and produced the most fruit; the most severely and most frequently pruned trees were smallest and yielded the least fruit.[1] It appears, although data are not available to support the conclusion, that the trees receiving moderate and regular pruning treatment produced

[1] The data have not yet been released for publication.

the most profitable crops. It should also be mentioned that prevalence of wind affected the experiment.

*Effects on full-bearing trees.*—The effects of pruning full-bearing trees have been studied by Shamel and associates with the Washington Navel orange (1919, 1925, 1927, 1929, and 1942), the Eureka lemon (1920*a* and 1933), and the Marsh grapefruit (1920*b*); by Cameron and Hodgson (1941, 1943) with the navel and Valencia oranges, the Eureka lemon, and the Marsh grapefruit; and by Reed (1917) and Surr (1919) with the navel orange. All the results have been more or less similar, depending on the nature and amount of the pruning applied. Only one of Shamel's experiments will be reviewed. On

TABLE 39

AVERAGE YIELDS, IN POUNDS PER TREE, OF PRUNED AND UNPRUNED NAVEL ORANGE TREES
(Experiment begun in 1914)

| Plot no. | 1915 | | 1916 | | 1917 | | Period, 1915–1929 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Pruned | Unpruned | Pruned | Unpruned | Pruned | Unpruned | Pruned | Unpruned | Loss (per cent) |
| 1 | 187 4 | 247 2 | 89 0 | 104.2 | 232.2 | 223.7 | 213.4 | 217.2 | −1.75 |
| 2 | 207.5 | 263.4 | 78.0 | 107 8 | 265.6 | 242 2 | 225.6 | 228.4 | −1.23 |
| 3 | 233.2 | 274.3 | 98.2 | 144.4 | 227.3 | 238.1 | 213.1 | 236.1 | −9.74 |
| 4 | 152.8 | 265.6 | 91.9 | 145.5 | 218 4 | 207.1 | 206.8 | 230.6 | −10.32 |
| 5 | 231.1 | 265.3 | 107 7 | 132.4 | 206.3 | 201.6 | 216.6 | 220.8 | −1.90 |
| 6 | 150.1 | 250 9 | 101.8 | 147.8 | 231 8 | 194.4 | 230.4 | 212.6 | +8 37 |
| Avg. | 193.7 | 261.1 | 94.4 | 130.3 | 230.2 | 217.8 | 217.6 | 224.3 | −2.99 |

Washington Navel orange trees twelve years old at the time the pruning was begun, pruning, from moderate to severe, by six commercial pruners was compared with no pruning. The first pruning by each pruner, in 1914, was more severe than any subsequent one. Plot 6 was pruned but once, owing to the death of the pruner. The other plots were pruned lightly or not at all after the original pruning until, in 1918, they received a moderate treatment; after that, with the exception of plots 2 and 4, they were not regularly pruned. In 1929 the dead wood was removed from the pruned trees. The unpruned trees were not so treated. The average yields for the first three years of the experiment and for the fifteen-year period, 1915–1929 inclusive, are given in table 39 (data from Shamel, 1927 and 1929).

It will be observed that during the first two years of the experiment all the pruned plots, as compared with the unpruned plots, showed decreased production, sometimes as much as 100 pounds per tree. By the end of the third year, however, in five of the six plots the pruned trees had passed the unpruned trees in yield, though the differences do not appear to be significant. After the moderate pruning of 1918, the pruned trees again yielded less than the unpruned trees; but within a few seasons they regained their relative position, and for the rest of the period their yields seem not to have differed significantly from those of the unpruned trees, though the average for the fifteen

years was 3 per cent less fruit. A more recent and much more extensive experiment gave similar results (Shamel and Pomeroy, 1942).

The experiment conducted by Cameron and Hodgson was concerned with the rate of top regeneration during the two-year period following three degrees of severity of pruning, which ranged from deheading to skeletonization. It was concluded that rate of top regeneration and resumption of bearing was inversely proportional to the severity of pruning.

TABLE 40

AVERAGE YIELDS, IN POUNDS PER TREE, OF OLD ORANGE TREES GIVEN ONE LIGHT OR HEAVY PRUNING*

| Year | Pruning | Plot 1 74 trees | Plot 2 80 trees | Plot 3 76 trees | Plot 4 80 trees | Plot 5 84 trees | Plot 6 70 trees |
|---|---|---|---|---|---|---|---|
| 1916 | Light | 157 | 161 | 160 | 165 | 140 | 104 |
| | Heavy | 70 | 88 | 83 | 82 | 68 | 63 |
| | Difference | 87 | 73 | 77 | 83 | 72 | 41 |
| 1917 | Light | 164 | 133 | 120 | 112 | 89 | 79 |
| | Heavy | 136 | 127 | 116 | 82 | 74 | 64 |
| | Difference | 28 | 6 | 4 | 30 | 15 | 15 |
| 1918 | Light | 52 | 56 | 54 | 58 | 59 | 55 |
| | Heavy | 46 | 52 | 40 | 47 | 45 | 52 |
| | Difference | 6 | 4 | 14 | 11 | 14 | 3 |
| 1919 | Light | 155 | 140 | 149 | 146 | 153 | 155 |
| | Heavy | 128 | 117 | 139 | 145 | 146 | 154 |
| | Difference | 27 | 23 | 10 | 1 | 7 | 1 |
| Total | Light | 528 | 490 | 483 | 481 | 441 | 393 |
| | Heavy | 380 | 384 | 378 | 356 | 333 | 333 |
| | Difference | 148 | 106 | 105 | 125 | 108 | 60 |

* Adapted from Surr (1919).

In the experiments reported by Reed (1917) and by Surr (1919), the trees were much older—24 years at the time of first pruning. For many years they had received little or no pruning and, at the time the experiment was begun, were in poor condition. Two kinds of pruning were compared, light and heavy, varying mainly in degree rather than in type. The lightly pruned trees were merely opened up by the removal of some of the branches. The heavily pruned trees were also reduced somewhat in height and their tops were opened up more. Only one differential pruning was given, after which the trees all received similar treatment, which consisted of a light annual thinning. Typical results from a part of the experiment are given in table 40.

Here again it will be noted that the principal reduction in yield occurred the first season after the pruning and that thereafter the difference tended rapidly to disappear. At the end of the four-year period, however, the heavily

pruned trees still averaged lower in yield than the lightly pruned trees, although the differences were no longer to be regarded as significant. Examination of the trees a year after pruning disclosed a larger amount of inside fruit wood in the heavily pruned trees than in the others—a condition which appeared to persist throughout the experiment, and which suggests that had the experiment continued longer the heavily pruned trees might eventually have surpassed the lightly pruned trees in yield and in better-quality fruit.

Of the general effect of pruning on citrus trees there can therefore be no question. Whether the trees be young or old, provided they are still in reasonable vigor, pruning is repressive of both growth and fruitfulness in almost direct proportion to the severity and frequency of the treatment.

*Effects on fruit quality.*—In several of the experiments cited, observations were made of the effects of pruning on fruit. Its influence on size is not clear. Shamel (1919 and 1925) reports no significant difference in size of fruit on the pruned and unpruned navel orange trees; but Surr (1919) reports that, the first season after pruning, the heavily pruned trees, with about half as much crop, produced markedly larger fruit than the lightly pruned trees, although this effect did not persist thereafter. It appears, therefore, that pruning may or may not affect the size of the fruit. The decisive factor appears to be the relation between the vigor of the trees and the amount of fruit they carry.

Pruning undoubtedly hastens the growth of lemons to picking size, and has long been a commercial orchard practice. Confirmatory evidence is cited by Shamel (1920*a*), who found that the average time between bloom and the attainment of a commercial picking size was nine months for lemons on pruned trees, as compared with eleven months on unpruned. Moreover, in his experiment he found that more fruit ripened before reaching picking size on the unpruned than on the pruned trees, an observation in agreement with the general belief of growers and packing-house managers.

The relation between pruning and the grade of the fruit, especially of lemons in windswept areas, has already been referred to. Although few experimental data are available to support this conclusion, there can be little question that the crops of unpruned trees, though they may be larger, often grade lower than those produced on pruned trees.

*Effects of heading and thinning.*—The pronounced differences in the growth responses produced by heading and thinning have long been recognized by citrus pruners and have been utilized in pruning practice. Indeed, all systems of pruning can be reduced to one or the other of these practices or to combinations of them, and a knowledge of their effects and responses is invaluable to good pruning practice.

The upright vegetative growth which characterizes one of the stages in the normal growth cycle of citrus shoots has already been described. How to control and utilize these growths is often the main problem for the citrus pruner. It has been pointed out that if exposure to light is favorable, these shoots if left alone will ultimately assume a desirable position and become useful fruit-bearing parts of the tree. In young trees, however, and under conditions of

accentuated vegetative vigor, growers are often unwilling to let them complete the normal growth cycle. It may, indeed, be inadvisable. In either event, there are only three methods by which they may be controlled: elimination, heading, or thinning. Heading, often referred to as "stubbing," means removing the terminal part of the shoot; the part remaining then ends with a cut. Thinning means removing parts of the branch, either laterals or terminals, in such a way as always to leave some terminal growth, whether it be the original terminal or a new one created by shortening into an already existing lateral. Obviously, thinning can be applied only to a branching shoot; heading can be applied whether or not the shoot is unbranched.

The effects of these two practices on the pruned shoot differ, and can best be understood by reference to certain of the physiological factors previously discussed and to work done by Halma (1926) and Elsawy (1927). It has long been recognized that when a citrus shoot is headed, new growth is produced only from buds close to the point of cutting. Commonly four or five shoots develop, one or two of which, usually the uppermost, outgrow the others and continue to extend vigorously. Eventually the most vigorous shoot becomes the new terminal and the others become lateral branches. Halma has shown that growth occurs only from the terminal buds because of some physiological influence exerted by the pruning, the effect of which is greatest near the point of cutting, and that the suppression of the shoots which later become laterals is caused by the dominance of the shoot which becomes the new terminal. Elsawy, studying the same response in the pear, has shown that the change probably causing this behavior is the conversion of the carbohydrates into soluble forms, which is most pronounced near the point of wounding. Whatever the cause and attendant phenomena may be, the heading process markedly accentuates the vegetative tendency in the shoot so treated.

The effect of thinning is very different. The resulting growth is much less vigorous and is better distributed. None of the buds are given the vigorous stimulus to growth which occurs in heading, and the physiological tendency or condition of the thinned branch is certainly much less affected.

Obviously, therefore, heading is the more wasteful practice to employ, since lateral fruit-bearing shoots are produced only at the expense of removing a sizable amount of growth, and for each new set of laterals heading must again be resorted to (fig. 145). Hence it should be avoided. Its extensive use in the pruning of citrus trees in the past, in California at least, has resulted in great loss to citrus growers.

## CITRUS PRUNING PROBLEMS AND PRACTICES

Problems and practices vary with age of tree, variety, condition of vigor, climatic and soil environment, and other particulars. These will be discussed first in the sequence in which they usually occur, and second with reference to special conditions which occasionally develop.

Pruning is essentially a tree-by-tree problem, and should so be regarded. No two trees are ever exactly alike; hence, the common practice of applying one over-all pruning program cannot reasonably be expected to yield satis-

factory results. The pruner should first master the underlying principles, so far as they have been established, and then study each tree as he comes to it. Parts should be removed only when a definite and valid reason exists for the removal. Many trees will need little or no pruning; others will obviously need treatment. The indiscriminate removal of a certain amount of the growth, regardless of the condition of the tree and its needs, cannot be too strongly condemned. This practice is altogether too common and has undoubtedly re-

Fig. 145. Young lemon tree pruned by heading back, which confines fruit production to the lower part of the tree but also keeps the top of the tree filled with vegetative growth. It is decidedly repressive to both growth and fruitfulness, and wasteful of growth.

sulted in important losses. Moreover, the pruner should not be hasty in his judgment. A branch removed cannot easily be replaced. If doubt arises, the safest procedure is to let it alone. There will always be valid and intelligent differences of opinion over the details of pruning, and the time will never come when two equally proficient pruners will prune exactly alike. Fortunately, in nature there is rarely only one best method to pursue. Usually there are a number of alternatives which in the long run will produce approximately the same result, whether good or bad.

THE NORMAL SEQUENCE IN NEED FOR PRUNING

*Pruning the young tree.*—In pruning the young citrus tree the two principal problems are establishing the head and developing a strong, well-

balanced system of framework branches. Most citrus trees come from the nursery with the heads already established at whatever height the purchaser may have designated, if the trees were grown under contract, or at the height commonly used in the locality in which the trees were grown. Unless the conditions and distance of shipment, and the pest-control treatment which may be required, render it inadvisable, the heads, if properly handled at the time of planting, can be maintained in the orchard; indeed, this is the usual practice. Where the trees are shipped long distances, however, and subjected to fumigation or dipping, it is often advisable to establish new heads after planting in the orchard; the trees are then merely cut back to an inch or two above the desired height and the new head is developed from the best-spaced four or five shoots that develop below the point of heading. When these shoots have reached a length of twelve to fifteen inches, at which time they ordinarily begin to droop and assume the horizontal position, they in turn should be headed, for the dual purpose, first, of providing rigidity of upright position for the scaffold branches, and second, of causing them to divide or branch. Nursery-grown trees are ordinarily at this stage of development when they are dug and transplanted to the orchard.

When citrus shoots are headed, usually it is only the buds close to the point of heading that will grow. This growth response makes it extremely difficult, in fact often impossible, to space the scaffold limbs more than a very few inches apart—which is the reason why the heads of citrus trees differ so much in this respect from those of other trees. But although this is theoretically objectionable, it is ordinarily of little practical importance for the reason that the scaffold branches are usually developed after the trees are planted and do not arise from the main trunk but come from the laterals resulting from the original heading.

In the training of the young tree two considerations are of primary importance; first, the prevention of the growth of too many scaffold limbs, and second, the spacing of these so as to prevent crowding in later years. With the lemon and certain strong-growing varieties of the orange, especially in hot, arid regions, these matters require attention or the trees are likely to develop long, weakly attached, and undesirable scaffold limbs which later cause the trees to spread and render them especially subject to wind injury (fig. 146). On the other hand, no greater mistake can be made than to prune off all these branches, since they provide the natural means by which the trees increase in size (figs. 147 and 148); excessive pruning will suppress desired growth. Objectionable or extra shoots of this kind should be removed by pruning or pinching before they have attained large size. With the lemon in particular it is sometimes necessary to shorten these parts, in which event they should, where possible, be cut back to laterals.

Among the commonest mistakes made in the pruning of young trees is the cutting off of the small drooping lateral branches arising from the original head. It is on these parts that the early crops are producing (see fig. 146), and to cut them off not only dwarfs the trees but also delays their coming into bearing.

Fig. 146. The characteristic growth of primary scaffold limbs in young Valencia orange trees in hot regions, when too many vegetative shoots are allowed to remain. In this illustration are shown strikingly (1) the fruiting habit of the small, pendant branches in young trees, (2) the dwarfing effect exercised by the vigorous upright daughter shoot on the terminal portion of the mother branch, and (3) the excessive growth in length made by vegetative shoots where they are shaded (caused here by crowding).

Aside from these considerations, which ordinarily can be accomplished with very little pruning, there is little need or justification for pruning young citrus trees.

*Pruning the bearing tree.*—During the early bearing years, the little pruning required will consist mainly in removing water sprouts from the trunk and

framework branches and, in the lemon especially, the most vigorous and poorly situated "riders" which occur on the outer parts of the trees. Again, it is clearly a mistake to remove all these shoots; only those which manifestly are too vigorous or poorly placed should be eliminated.

As the trees reach full-bearing age, the conditions begin to develop which require more attention to pruning. With the orange and grapefruit, ordi-

Fig. 147. Severely and regularly pruned young Valencia orange tree. Growth has been suppressed by excessive pruning, which consisted in the removal of all vegetative shoots. See figure 148 for comparison.

narily the first of these to occur is density of growth and consequent decline of the older interior bearing wood in the lower parts of the tree, a condition which thereafter requires attention. Solution of this problem requires the annual removal of the oldest and most useless of these parts, together with a judicious thinning of the rest. The removal of the declining or worn-out lower branches can best be done by cutting from beneath, leaving the upper and newer parts to replace the ones removed—a practice popularly referred to as "undercutting." In this way the bearing efficiency of the lower part of the tree can be maintained almost indefinitely.

Fig. 148. Unpruned young Valencia orange tree of the same age as that shown in figure 147. The growth of this tree should have been controlled by light pruning or pinching.

With the lemon, one of the first conditions to develop which requires pruning, in addition to that just discussed, is the spreading and drooping of the upper branches, which arises from the natural habit of growth and the weight of the fruit. Unless these branches are reduced in length, the inevitable result

is a large, spreading tree subject to the objections already discussed. The only way to prevent it is to shorten the most vigorous of these branches by cutting to laterals; if this is regularly and properly done, it accomplishes not only the development of a low-spreading, compact form, but also the periodic renewal of the bearing wood in the upper part of the tree. On the other hand, if an attempt is made to solve the problem by heading back or "shearing," the condition is only made worse; the top of the tree becomes filled with vigorous vegetative shoots which not only do not bear, but also shade and stunt the growth in the lower part of the tree.

As the trees grow older—orange and grapefruit especially—it becomes increasingly necessary to thin the outer "shell" of foliage and thus permit the entrance of sunlight for the purpose of encouraging the development of fruit wood on the interior parts. Opinions differ concerning the best means; most favored is a light annual thinning. It is clearly a mistake to thin by removing large branches in the tops of the trees; this not only exposes the framework branches to sunburn, but also generally fails because the vigorous growth stimulated in the vicinity of the cuts soon fills up the "holes" made.

It also becomes increasingly advisable, as the trees age, to renew gradually the fruit-bearing wood in the upper parts, especially in orange and grapefruit trees where the renewal is not normally accomplished by shortening the branches. This can best be done at the same time that the outer growth is thinned, by gradually removing the small older terminal branches in the upper part of the tree. In the lower part, it is of course done by thinning and removing the declining branches. As the older branches are forced down by the weight of the fruit and growth above, it becomes desirable to "raise" the trees, which is accomplished by the removal of these branches by "undercutting."

*Practices to avoid: summary.*—There is nothing to justify the heavy or severe pruning of normal healthy trees; injury and loss resulting therefrom have been amply demonstrated. Heading back or "stubbing" is rarely productive of benefit; it should most assuredly be employed with caution. "Shearing" and "topping" are merely bulk applications of heading and hence are equally objectionable. "Undercutting" young trees results in lessened and slower bearing; it should not be practiced. Opening the tops of bearing trees by removing large branches is a dangerous and ill-advised practice. Wounds should not be made improperly, nor should stubs be left; these are not only evidences of poor workmanship, but also productive of undesirable results. All cuts should be made close to the parent limb, and if possible in the vertical plane, as the wounds then heal over more rapidly. Stubs should never be left, as invariably from them will arise clumps of vegetative shoots, often referred to as "sucker nests," which will later require removing.

## SPECIAL PRUNING PROBLEMS

The discussion thus far has assumed that the trees have been well cared for, in pruning as in other respects. But neglect or injury may have done damage that pruning will help correct. A single pruning will rarely do. To bring the trees back into good condition will require a number of prunings

distributed over several seasons and, often, radical changes in other orchard-management practices. The general objective should be to bring about the desired improvement with the least possible disturbance to the physiological balance in the trees. This usually means not only several prunings, but also,

Fig. 149. Changing from heading-back pruning of lemons to thinning. The most vigorous and undesirably placed shoots are removed. The others are left *until they produce laterals when they are shortened-in, or not,* as conditions may warrant.

for a distribution of response throughout the tree, the making of numerous small cuts and the removal at any one time of only a small amount of growth.

*Changing from heading to thinning.*—Changing from a heading-back system to one of thinning—a method of treatment applicable only to lemon trees —usually requires a number of prunings distributed over several seasons. At the first pruning only the most vigorous vegetative shoots should be removed, but care should be taken to make the cuts close to the parent limbs in order to minimize the subsequent production of similar shoots (fig. 149). At each successive pruning the less vigorous vegetative shoots should be left. The resulting

growth will then become less vegetative until the trees are finally in good balance. Occasionally it will be necessary to leave rather vigorous shoots, but, where possible, these should be shortened-in to laterals. If laterals are not present it is not advisable to resort to heading back. Allowing these shoots to go unpruned for a few months will expectably result in a growth of laterals that can be used later in the shortening-in process. Once the trees are in balance again, the usual pruning will suffice to keep them in good condition.

*Reducing oversized trees.*—With lemons, this problem usually relates both to reduction in height and shortening-in of the long, spreading, more or less horizontal parts. With the orange, it usually means lowering the tree height—which in the Valencia variety results from the upright habit of growth, and in the navel from the development of a second and higher top when a strong-growing water-sprout branch becomes dominant. With the lemon and Valencia orange, or other varieties of similar growth, it means the shortening-in of the long parts, cutting always to laterals, however. The removal of some of the older and least vigorous branches may also be advisable, but should be done with caution. Too much cutting at any one pruning may result in the production of a large amount of vegetative growth which, unless thinned, will eventually produce a similar undesirable condition. If the pruning is done properly, however, the trees can be maintained in good balance and still be materially reduced in height or size.

The "two-story" or "sucker-top" navel orange tree presents a difficult problem. (See fig. 144, p. 419.) If the water-sprout limb is large and occurs in the upper part of the tree, it is probably best to limit the pruning to merely shortening-in the terminal growth as far as is practicable. If the limb is not too large and the tree is comparatively young, it may sometimes be removed with advantage, especially if other upright framework limbs are available. To remove large "sucker tops" from old trees, however, is usually a mistake, since the condition resulting is often as bad as the original condition, or worse.

*Pruning neglected trees.*—When the adverse condition is merely of impaired vigor resulting from neglect, it is always advisable, before resorting to pruning, to remedy the conditions that have caused the decline. Usually, a season or two must lapse before the natural recovery will occur. In general, therefore, it is inadvisable to do much pruning when diminished vigor of the trees is the only undesirable condition. And it should be remembered that the heavy pruning of neglected trees which many growers have practiced—and which, it must be admitted, often appears to be the logical treatment—has resulted in injury and lowered yield.

It is, of course, not injurious to remove the dead wood from neglected trees, and a moderate amount of undercutting and thinning to remove dead or declining growth may sometimes be advisable.

When neglected trees have been restored to normal vigor, it becomes important gradually to eliminate the old and declining parts in order to provide for the maintenance of health and vigor in the new growth.

*Pruning for rejuvenation.*—Pruning for the rejuvenation of old citrus trees is a practice not yet widely applied in California. Old-age decline of citrus

trees is as yet rare in the citrus orchards of this state. Some old and unproductive trees have, however, benefited from pruning—indicating that pruning for rejuvenation may assume importance in the future.

In Spain, Italy, and elsewhere, renewal of the tree tops has been brought about by decapitation, sometimes referred to as "deheading," an extreme

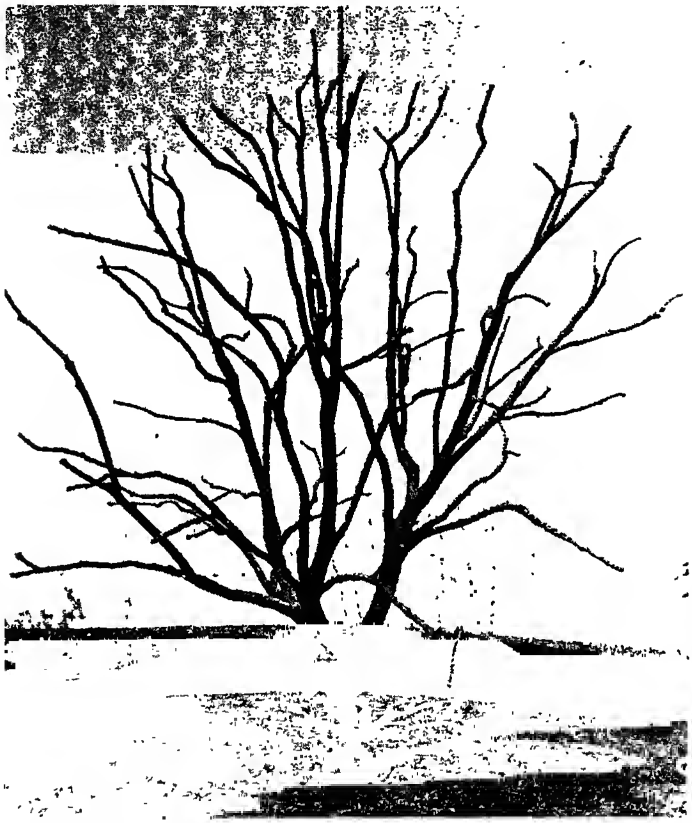

Fig. 150. A skeletonized Washington Navel orange tree. This method of pruning results in rapid regeneration of new top and resumption of fruiting. See figures 151 and 152.

measure which, unless carefully followed up, is sure to result in an undesirable framework, and which will delay for some time the resumption of profitable bearing (Cameron and Hodgson, 1941).

In California, a method is employed that may be called "skeletonization." The entire outer shell of growth and all branches less than an inch in diameter are removed; what remains is the now skeleton-like framework system (fig. 150). As this is thinned and reduced in height by the elimination of the upright branches in the tops, what then remains is the simplest possible skeleton

on which to build an entirely new fruiting system. The growth response to this treatment is distributed through the entire system of framework branches instead of localized in some parts of the tree, and as a result the growth that

Fig. 151. Washington Navel orange tree skeletonized in February, 1939. Photographed in April, 1940. Note character of growth and amount of bloom. See figures 150 and 152.

puts out is usually not markedly vegetative, and soon, ordinarily within a season or two, becomes fruitful (Cameron and Hodgson, 1941) (figs. 151 and 152). Although this system necessitates more cuts and requires more time and consequently is more expensive than deheading, the additional cost is much more than offset by the quick recovery and resumption of bearing.

***Pruning trees injured by frost or wind.***—How and when to prune frost-injured trees are questions periodically of interest to citrus growers the world over. Experience in California and Florida has shown that pruning as soon

Fig. 152. Washington Navel orange tree skeletonized in February, 1939. Photographed in January, 1941. Note the crop, two years after pruning. See figures 150 and 151.

as the frost is over is a mistake, since one cannot determine then, or perhaps for months afterward, the degree of injury. Moreover, it has been shown that if the injured trees are left unpruned, recovery is effected more rapidly than if pruning is done (Webber, 1896; Webber *et al.*, 1919, p. 286). Hence frost-injured trees should not be pruned until several months after injury; it is

best, if one can, to let them go a full season before pruning. The effect of injury from frost, if more severe than defoliation and the killing of tender shoots, resembles the effect of heading back or shearing (fig. 153). The response of the frost-injured tree—namely, vegetative growth—is the same as that of the headed-back tree. To prune soon after a freeze, therefore, instead of aiding in restoring the balance between root and top, only further aggravates the lack of equilibrium.

Fig. 153. The growth response of frost-injured lemon trees is similar to that of heading-back pruning, as is also the pruning problem created. See figures 145 and 149.

The problem of pruning the frost-injured tree is in most respects similar to that (discussed above) of changing from heading to thinning. The only difference is that when the trees have returned to balance, the parts where bark injury has occurred must gradually be eliminated. Appropriate methods for so doing are described elsewhere (chap. xviii).

Trees injured by wind burn or scorch should receive similar treatment. Many of the defoliated and injured branches will eventually recover if given a chance to do so, though recovery is often slower than from frost injury. Branches that fail to recover satisfactorily may then be pruned out with a minimum loss of foliage and a minimum of disturbance to physiological equilibrium.

## PROTECTING THE PRUNED TREE

*Sunburn.*—The bark on normally shaded limbs in citrus trees is very susceptible to injury from sunburn, and when the injury is extensive a satisfactory recovery is rare. A few hours' exposure to the hot sun may cause irreparable injury. Protecting the pruned tree against sunburn is therefore important, especially in arid subtropical regions. Wherever pruning results in exposing framework branches to direct sunlight, though for only a few hours in the day, the exposed limbs should be thoroughly coated with whitewash.

*Treatment of wounds.*—Large wounds made in pruning permit the entrance of decay-producing fungi which under favorable conditions occasion heart rot of the trees and may ultimately cause decline. In hot, dry regions the danger of decay is not so great, though always present. It is desirable, therefore, both as a means of protection and as encouragement to rapid healing-over, to cover with an antiseptic dressing all cut surfaces that exceed an inch or two in diameter. The application of a disinfectant[1] prior to the use of a wound covering is advised by some; others say that just as good results will be had without disinfectants. It is advisable to permit a wound to dry thoroughly before applying a compound.

A satisfactory wound dressing should be cheap to apply, and permanent. It should lack penetration, and be elastic. Whitewash, bordeaux paste, lead paints, and varnishes or shellacs do not satisfactorily meet these requirements, since they soon dry out, crack, and lose their protective qualities. Grafting wax, excellent in many respects, is too expensive at the usual prices for beeswax. Most promising, and most used, are the asphaltum compounds.[2] It is important to make certain that all large wounds are well coated with a dressing, and that it is renewed occasionally while the wound is healing.

## PRUNING TOOLS AND EQUIPMENT

Without good tools it is difficult, if not impossible, to do satisfactory pruning. Moreover, it is necessary to keep the tools in good condition. A wide variety of tools and equipment may be found in use by citrus pruners, but experience in California has indicated that the following are best adapted to their needs:

1. A short, light, self-supporting stepladder.
2. A pair of gauntlets.

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[1] One of the best that can be recommended is mercuric cyanide dissolved in equal parts of ethyl alcohol and water in the proportion of 1 part of mercuric cyanide to 1,000 parts of the alcohol-water solution.

[2] Asphaltum roof paint, without the thinning oil, has been used with good results. Grade B asphaltum, a liquid form, is also popular. Liquid preparations made by dissolving asphaltum in gasoline or distillate have been used, but seem often to cause injury from the penetration of the solvent. Melted asphaltum has been used, but is often injurious and always inconvenient in handling. Boiled tar has also been used. There are a number of commercial preparations on the market, the most promising of which is a recently developed dressing, "Tree Seal," which is apparently a *water emulsion of asphaltum* and can therefore be applied successfully even to wet surfaces.

3. A pair of strong 6-inch hand shears.
4. A leather case for the shears, attached to the belt.
5. A folding pruning saw of the pull type, with a curved blade.
6. A 14-inch swivel-blade bracket saw (with extra blades).
7. A bucket of pruning compound, and a brush.

The saw in most general use is a pull saw with a blade 12 to 18 inches long, the cutting edge of which has a curved shape. There are numerous saws of this type on the market; some of them are excellent and others unsatisfactory. The curve of the cutting edge must not be too great, and the form and set of the teeth must be such as to clear the cut readily of sawdust. For the removal of large crowding limbs a different type of saw is desirable; the one most used is a bracket saw having narrow clearance at the front and a 12- to 14-inch swivel blade. With this saw, which is sometimes referred to as the California pruning saw, it is possible to work in the most acute angles made by the framework branches.

## DISPOSAL OF PRUNINGS

Because the trees are evergreen and are extremely sensitive to heat, it is not advisable to burn heavy prunings in the orchard, either on the ground or in portable burners—both of which methods are commonly resorted to in deciduous orchards and vineyards.

When the branches removed are large and waste space is available for burning, it is customary to drag or haul the prunings from the orchard and burn them. If space for burning is not available, as in the closely planted orchard regions of California, all but the larger branches are commonly cut up and incorporated in the orchard soil. The cutting is usually done by means of hand-lopping shears which, if properly designed and strongly made, will readily cut branches that are as much as two inches in diameter. On large properties the prunings are sometimes run through heavy machine cutters of the ensilage type mounted on sleds or wagon beds.

## TIME AND FREQUENCY OF PRUNING

Few data are available on the effects of pruning citrus trees at different times of the year. In California, reasons of convenience mainly dictate the time when pruning treatment is applied; in Florida, the factor of safety appears primary. The least physiological repression, and hence the best results, should be obtained when pruning is done at or soon after the period of maximum carbohydrate storage, which in California is late winter and early spring (Cameron, 1933). That the rate of top regeneration is most rapid in trees pruned in late spring and early summer, and least rapid in trees pruned in the fall, has recently been reported by Cameron and Hodgson (1943). Shamel and Pomeroy (1942) have also reported results which suggest that pruning done after the trees bloom may be less repressive to yield than earlier treatment.

Moreover, it is generally agreed that pruning in late summer or early fall is undesirable because, as has long been observed, treatment at these seasons causes the trees to grow late in the fall and renders them more susceptible to

injury from frost. It is equally well established that the opening up of the trees which is attendant on fall or winter pruning materially increases the hazard of frost injury to the bark on the larger branches (Webber *et al.*, 1919, p. 279). Moreover, the sensitivity of the bark of shaded limbs to injury from sunburn, already noted, makes it inadvisable to do heavy pruning in the hot summer and fall months.

The best time for pruning, therefore, is undoubtedly after danger from frost injury is past, in early spring, and before the advent of hot weather, in early summer. Unfortunately, this is usually a period of great activity in other orchard-management operations, and pruning is often delayed until later in the season.

In California, the time of pruning is most often affected by the presence of maturing fruit on the trees. Thus, with the navel orange and winter grapefruit the common practice is to prune the trees after the crop is harvested, that is, in the winter and spring and before the trees come into bloom. With the lemon, Valencia orange, and summer grapefruit, however, both young and ripe fruit are on the trees much or all of the year and hence the pruning is generally done when the amount of salable fruit is least, usually in late summer.

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## Chapter X

# PRINCIPLES AND METHODS OF IRRIGATION

BY

MARTIN R. HUBERTY

Irrigation is one of the world's oldest agricultural practices. On the American continent it antedates historical records: in the southwestern part of the United States may be found the remains of what were once substantial irrigation works developed by the Pueblo Indians before the days of the earliest Spanish missionaries. Of the approximate 200,000,000 acres of the world's irrigated area, about 10 per cent is in the United States. California, with an irrigated area of about 5,000,000 acres, has only about one-tenth of that of India or China.

The permanence of agriculture under irrigation is questioned. Although it may not have been fully demonstrated that a permanent and enduring agriculture is possible under irrigation, a majority of those who are associated with the development of irrigation enterprises are certain that with the aid of science, together with an intelligent use of water, some causes of past failures can be avoided.

Irrigation may be defined as the artificial application of water to the land. Simple as this definition may seem, and old as the practice is, irrigation must be recognized as one of the least understood of present-day agricultural operations.

Although irrigation is usually associated with the application of water to the soil as a means of promoting plant growth, operations such as the flooding of lands for leaching purposes may be classed as irrigation.

In its broader sense, irrigation may be divided into three phases: engineering, economic, and agricultural. This chapter deals primarily with the agricultural phase, especially as related to citrus production. It includes a brief discussion of the measurement of irrigation water and the units of measurement used in the United States; preparation of land for irrigation; installation and maintenance of distributing systems; methods of irrigation as applied to citrus crops; monthly and seasonal water requirements of citrus crops, and their response to variable irrigation treatment; and a discussion of soil moisture, its movement, and its relation to the growth and production of citrus trees.

## MEASUREMENT OF IRRIGATION WATER AND UNITS OF MEASUREMENT

In the early days of irrigation development, water was plentiful, and as long as streams carried a supply sufficient to meet the needs of agricultural lands bordering their courses little attention was paid to the magnitude of water diversion for crop production. As the number of users increased, the

question of "priority" of water rights arose. This led to the necessity of determining the amount diverted by each user and to the adoption of certain units of measurement by which exact comparisons could be made of the quantities used. These units may be divided into two general groups: units of volume, and units of flow. The former units are used in expressing the quantities of water at rest; the latter, in expressing the rate of flow of water in motion.

The common units of volume are: cubic foot (cu. ft.), gallon (gal.), acre-inch (ac. in.), and acre-foot (ac. ft.). An acre-foot is the volume necessary to cover one acre to a depth of one foot. This is equivalent to 43,560 cubic feet.

Units of flow commonly used in irrigation practice include cubic foot per second (c.f.s.), gallon per minute (g.p.m.), and miner's inch (mi. in.).

The cubic foot per second is the standard unit of flow, especially for large flows. It is equivalent to 448.8 gallons per minute, but the figure 450 is normally used in making conversion to or from gallons per minute.

Gallons per minute is often used in expressing small flows. Pump discharges are usually expressed in this unit.

The miner's inch, as the name implies, was adopted from the mining industry, in its development in the western United States. Here it was often necessary that the waters of a stream be divided among several users. In meeting this demand equitable division was based on measurement, which necessarily needed to be simple, inexpensive, and positive. This led to the adoption of the miner's inch, defined as the quantity of water flowing freely through an opening with an area one inch square under a designated head measured from the center of the opening to the upstream water surface. As the use of this unit increased, various states passed laws designating the value of the miner's inch in terms of cubic feet per minute or fractions of cubic feet per second; as, for example, 50 miner's inches = 1 c.f.s. in Utah, Idaho, New Mexico, Oregon, and Washington, while 40 miner's inches = 1 c.f.s. in Arizona, Montana, and Nevada, and 38.4 miner's inches = 1 c.f.s. in Colorado.

In California two values are recognized, as follows: (1) the statute inch, defined as a flow of 1.5 cubic feet per minute, which equals $\frac{1}{40}$ c.f.s.; and (2) the customary or southern California miner's inch, which is defined as the quantity of water, flowing freely through an opening one square inch in area under a pressure[1] of four inches measured from the center of the opening, which equals $\frac{1}{50}$ c.f.s. Table 41 gives approximate equivalent values of different units of measurement of irrigation water.

Growers of citrus or other crops are often interested in converting the measured flow of irrigation water during a specified time into average depth of water over area considered, sometimes referred to as acre-inches or acre-feet per acre. This conversion is easily accomplished through the use of the formula:

$$\text{Approximate average depth in inches} = \frac{\text{Flow in c.f.s.} \times \text{hours run}}{\text{area in acres}}.$$

[1] In several localities in California local practice determines the pressure used.

If the flow is given in gallons per minute or in miner's inches, it should first be reduced to cubic feet per second or fractions thereof. For example, if one wishes to determine the average depth of water applied when a flow of 30 customary miner's inches is applied for 72 hours to an orchard of 12 acres:

$$\frac{\frac{(30)}{(50)} \times 72}{12} = 3.6 \text{ average depth of water in inches.}$$

Theoretically the measurement of water is a simple operation, but practically it is often complex, and confusing to the water user. This is due to the wide variation in conditions governing the diversion, division, and application of water to the land. The ideal measuring device should be low in cost, easy to install and operate, and accurate to a degree comparable with the value of the water, and where possible the measurement should read in terms most easily converted into the unit used as a basis for payment.

TABLE 41

CONVERSION TABLE FOR UNITS OF FLOW*

(Equivalent values are given in the same horizontal line)

| Cubic feet per second | Gallons per minute | Million gallons per day | Southern California miner's inches | California statute miner's inches | Acre-inches per 24 hours | Acre-feet per 24 hours |
|---|---|---|---|---|---|---|
| 1.0 | 448.8 | 0.646 | 50.0 | 40.0 | 23.80 | 1.084 |
| 0.00223 | 1.0 | 0.00144 | 0.1114 | 0.0891 | 0.053 | 0.00442 |
| 1.547 | 694.4 | 1.0 | 77.36 | 61.89 | 36.84 | 3.07 |
| 0.020 | 8.98 | 0.0129 | 1.0 | 0.80 | 0.476 | 0.0397 |
| 0.025 | 11.22 | 0.0162 | 1.25 | 1.0 | 0.595 | 0.0496 |
| 0.042 | 18.86 | 0.0271 | 2.10 | 1.68 | 1.0 | 0.0833 |
| 0.504 | 226.3 | 0.3259 | 25.21 | 20.17 | 12.0 | 1.0 |

* From California Agric. Exper. Sta. Bull. 588, by J. E. Christiansen.

In the measurement of flow in irrigation systems a wide variation of measuring devices can be used, depending upon the quantity of water to be measured and the conditions under which the measurement is to be made. These devices include meters, the measuring flume, free-flowing and submerged orifices with fixed or adjustable openings, weirs, various types of miner's-inch boxes, etc.

No matter what method is used, the accuracy of measurement should be in harmony with the value of the water. Where water is plentiful and cheap, expensive measuring devices and extreme accuracy are not warranted. Where it is scarce or expensive, its value may justify expensive devices from which accurate measurements can be obtained. A full description of all the various devices and conditions under which they should be used is not essential here. Texts on irrigation practice cover the subject thoroughly, and numerous bulletins dealing with the various phases of the subject have been issued by the U. S. Department of Agriculture and the Agricultural Experiment Stations of the western states. Bulletins by Cone (1917), Christiansen (1935), and Parshall (1941) are recommended to readers interested in the measurement of water on the farm.

## PREPARATION OF LAND FOR CITRUS IRRIGATION

Owing to the relatively shallow soil in many of the citrus areas, caution is necessary in the removal of the top soil in the preparation of land for citrus irrigation. From the deeper soils of the sandy and sandy loam types which are highly permeable throughout their entire depth a much greater depth of surface soil can safely be removed without permanent injury to the productiveness of such soils than from fine-textured soils or soils with claypan or hardpan. In general, the very fine-textured soils take water very slowly and are not conducive to deep root penetration.

It is usually much more desirable to modify the method of irrigation to suit the topography of the land than to change the land to fit any particular method of irrigation or irrigation layout.

In crop production the object of irrigation is to maintain a desirable supply of soil moisture in the soil mass occupied by the root systems of the plants. Uniformity in soil-moisture distribution naturally tends toward producing uniformity of growth and an increase in crop yields. Obviously, a more uniform soil-moisture distribution is obtainable in soils which have been well prepared for irrigation than it is possible to obtain in those that have uneven topography and undesirable slopes. Well-prepared land tends toward economy in water and labor required, and toward improvement of irrigation practice.

Land leveling does not mean that extensive areas should be reduced to level surfaces or uniform grades. In the main, it consists in correcting minor local unevenness without materially changing the general slopes and contour of the land. Where larger fills are made, allowance should be made for settling.

The extent to which leveling is justified depends upon such factors as soil type, method of irrigation to be used, method of water delivery, size of irrigating stream, cost of water, cost of leveling, and value of the crops produced. No rules can be laid down as a definite guide to the preparation of land for irrigation. Each piece of land to be leveled is a separate problem. If land leveling is to be done, it should be completed before the orchard is planted or the water distributing system installed.

## DESIGN AND INSTALLATION OF THE DELIVERY SYSTEM

In the irrigation of citrus orchards in the southwestern United States a large proportion of the water used is applied through concrete pipe systems.

In California citrus orchards there is a very large investment in concrete pipe distributing systems. Concrete pipe is not adapted to use under gravity irrigation systems delivering silty water at low velocity, nor to high pressures unless the pipe is adequately reinforced.

The development of the modern concrete pipe distributing systems was brought about because it was necessary or desirable to eliminate waste land, reduce waste of water, regulate flow more closely, especially in furrow irrigation, and reduce the labor costs of irrigation. Where flooding by borders

or basins can be done without injury to the trees, where water is plentiful, where grades are favorable, and where seepage losses are not excessive, earth ditches are often used for the delivery and distribution of water to citrus orchards. In the development of better irrigation methods, however, timber and various types of masonry flumes have replaced the open ditch, and these in turn have been replaced by concrete pipe.

Space does not permit a complete discussion of all phases of design and installation of concrete pipe delivery systems. However, some of the more important aspects will be considered briefly.

Because the installation of a concrete pipe system is a long-time improvement and represents a substantial investment, its design warrants careful consideration. The problem consists of determining the proper size of pipe, the best location for the main delivery and distributing lines, and the most desirable types of distributing stands and regulating gates and valves.

In most localities where concrete pipe is in common use, machine-made pipe of good quality is available. In general, this is of better quality than that which is hand-tamped. Because the manufacture of good pipe requires proper equipment and experience, the practice of manufacturing homemade pipe on the farm is not recommended. High-quality pipe is usually available in most localities at reasonable cost. A reliable contractor is the best insurance for a satisfactory job.

Where large tracts are to be placed under pipe irrigation it is advisable that a contour map be made of the area, with the contour intervals sufficiently close to permit an accurate location of mains and laterals. Such a map is also of material assistance in land leveling.

The size of the pipe to be used will depend on the quantity of water to be carried in the line, the grade on which the pipe is laid, and the smoothness of the interior surface of the pipe. In the smaller installations, contractors often guess at the size of pipe to be used, paying little or no attention to changes in grades. This practice may necessitate building division boxes and pressure stands to an inconvenient height. It is good practice to keep pressures as low as possible, provided the cost is kept within reasonable limits.

The quantity of water required to irrigate any particular group or block of trees served from a single line might vary widely from year to year. If, for example, furrow irrigation is used, the number of furrows per tree row will increase from two during the first year after the orchard is planted to a probable maximum of eight as the orchard approaches full bearing, with a corresponding increase in the total water requirement as the size of the trees increases from year to year. At this time the full carrying capacity of the pipe line will be utilized. However, the actual size of the irrigation stream and the period of application of water will vary from year to year as changes are made in orchard soil-management operations other than irrigation.

In the production of cover crops in young orchards a desirable rate of flow may exceed the maximum required for irrigation of the trees alone. It is necessary, therefore, that pipe lines be ample to handle adequately the maximum flows of water to be delivered.

In large tracts, and where the topography of the land permits, the distributing system is usually laid out in five-, ten-, or twenty-acre units. This is an advantage in keeping records of yields or quantities of water applied, and is particularly advantageous if, in later years, the orchard is subdivided into smaller tracts.

The spacing of delivery lines within the tracts depends upon the slope of the land and the soil characteristics. In a 10-acre unit of land with a length and width of 660 feet, two or three cross lines are usually used, spaced 330 or 220 feet apart. In recent years the tendency has been toward the use of shorter runs, the length of which is influenced by the two factors stated above. Obviously, the fine-textured soils on the steeper grades are more favorable for the use of the longer runs. Light soils on very flat grades are particularly difficult to irrigate without excessive penetration at the upper end of the run, and often require an extremely close spacing of the pipe lines. It is at times desirable to change the direction of the runs within an orchard to take advantage of the changing slope of the land.

Where the water is available on demand, variations in soil type within short distances have resulted in the practice of "spot" irrigation, in which different parts of the orchard are irrigated at different times and with varying frequencies in irrigation. This practice requires that the pipe system be extensive enough to permit water to be delivered to these particular areas of varying soil types. A saving in installation costs can be effected if this need can be anticipated at the time the original installation is made.

*Distributing hydrants.*—The type and size of distributing hydrant should be governed by the method of irrigation to be used and the quantity of water to be delivered through the individual stand. Where the flooding methods are used (borders or basins), larger flows are required, which in turn call for larger openings. Alfalfa valves with openings of about the same diameter as the riser pipe may be justified, and are desirable where the soils are so porous that portable pipe is required in the delivery of water to individual basins.

In furrow irrigation a number of different types of distributing stands are used, the more common of which are the capped stand and the valve-controlled hydrant. The capped stand as shown in figure 154 is probably the most extensively used and is especially adapted to distribution under low pressures. It has the advantages of freedom from debris, low installation cost, accurate regulation, and small leakage losses when heavy, close-fitting outlet gates are used. The principal disadvantage in the use of this type of stand is that the outlet gates are under pressure during the entire operation period of the line, and when leaks occur a considerable waste may take place. The use of cheap, lightweight, poorly made outlet gates should be avoided.

The valve-controlled hydrant consists of a short riser connected to the underground lateral and fitted with a small valve. The riser discharges into a larger chamber—the receiving chamber—which is fitted with the required number of small regulating gates. Receiving chambers are of different sizes and shapes, the circular shape being generally preferred because it is more

easily manufactured. A spacing of the outlet gates in the receiving chamber amounting to at least six inches is desirable since it lessens the tendency of the water to break from the furrows where they are connected to the stand.

Special types such as that shown in figure 155, in which the regulated flow is discharged directly into the furrows, are sometimes used. The spacing

Fig. 154. Capped stand, used under low water pressure.

of the distributing gates in the delivery pipe is made to conform to the furrow spacing. The advantage of this type of distributing device is that the furrowing can be continuous throughout the entire length of the orchard and the labor of connecting the furrows to the distributing stands is eliminated.

Where steep hillsides are to be irrigated, distributing stands of special design may be necessary in order to assure an even flow under conditions of variable pressure in the delivery lines. Various types of overflow stands and relief stands as described by Huberty and Brown (1928) are used to keep

Fig. 155. Special type of delivery outlet for direct application of water into the furrows.

the pressure within desired limits. Where excessive grades are encountered the usual practice is to use overflow distributing hydrants, in which the pressure is relieved at each tree row. Bulletins by Stanley (1921) and Smith (1918) contain further information on the manufacture and use of concrete pipe for irrigation.

Table 42 (p. 454) gives values for head losses in concrete pipe resulting from friction. The data are from the experiments of Scobey (1920).

## METHODS OF CITRUS IRRIGATION

Irrigation is a process of artificial soil-moisture replenishment. Ideal irrigation consists in wetting the soil mass occupied by the root system of the irrigated crop without excessive penetration below the root zone and without excessive waste by runoff from the area irrigated.

The general conditions which prevail in a majority of the irrigated citrus areas of relatively high land values and limited and expensive water supplies compel a higher degree of efficiency in the use of irrigation water than is usually found in other irrigated crop areas. Efficient irrigation is only possible through the use of proper methods of application.

The main factors governing the choice of methods are: (1) size, spacing, and system of planting of the trees; (2) size of stream and duration of flow; (3) method of delivery (open ditch, flume, or underground pipe); (4) soil characteristics; (5) topography, or slope of the land; and (6) depth of water to be applied. With the wide variation in particulars such as the fluctuation in flows and the changes in soil type or topography often found within small areas, it is impossible to formulate a set of rules governing the choice of the proper method of irrigation. Following is a brief description of the methods of irrigation of citrus orchards and the conditions under which they are generally used. These methods fall into three general classes:

1) Subirrigation, by which the water is applied below the ground surface in deep ditches, or through porous or open-jointed pipe lines, or through pressure lines with shielded nozzles—a method not widely employed in the irrigation of citrus orchards.

2) Surface irrigation, by which water is transported on the soil surface by flooding or in furrows.

3) Sprinkling, by which the water is distributed from sprinklers or nozzles.

### SUBIRRIGATION

Subirrigation may be either natural or artificial. Natural subirrigation is the supplying of moisture by means of capillary rise from an established water table. If the water level is high enough to supply the moisture needs of the surface roots, accumulations of salines on the soil surface will probably result in arid climates. If the saturated zone is too far below the soil surface, irrigation water will have to be added to the surface of the soil. A fluctuating water table is unsatisfactory for perennial crops. When the water level lowers, the root system grows downward; and when it rises again, the saturation of the soil destroys the new root growth if the high water level

TABLE 42

FRICTION LOSS IN CONCRETE IRRIGATION PIPE IN FEET PER 1,000 FEET*

| Flow | | | | Pipe diameter in inches ($d$) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cu. ft. per sec. | So. Calif. miner's inches[a] | Statute miner's inches[b] | Gallons per minute | 6 | 8 | 10 | 12 | 14 | 15 | 16 | 18 | 20 | 21 | 24 | 30 | 36 |
| 0.1 | 5 | 4 | 45 | 0.3 | 0.1 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | ... |
| 0.2 | 10 | 8 | 90 | 1.1 | 0.2 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | ... |
| 0.3 | 15 | 12 | 135 | 2.6 | 0.6 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | ... |
| 0.4 | 20 | 16 | 180 | 4.6 | 1.0 | 0.3 | .... | .... | .... | .... | .... | .... | .... | .... | .... | ... |
| 0.5 | 25 | 20 | 225 | 7.2 | 1.6 | 0.5 | .... | .... | .... | .... | .... | .... | .... | .... | .... | ... |
| 0.6 | 30 | 24 | 270 | 10.4 | 2.3 | 0.7 | 0.3 | .... | .... | .... | .... | .... | .... | .... | .... | ... |
| 0.7 | 35 | 28 | 315 | 14.0 | 3.2 | 1.0 | 0.4 | .... | .... | .... | .... | .... | .... | .... | .... | ... |
| 0.8 | 40 | 32 | 360 | 18.4 | 4.1 | 1.3 | 0.5 | 0.2 | .... | .... | .... | .... | .... | .... | .... | ... |
| 0.9 | 45 | 36 | 405 | 23.4 | 5.2 | 1.0 | 0.6 | 0.3 | .... | .... | .... | .... | .... | .... | .... | ... |
| 1.0 | 50 | 40 | 449 | 28.8 | 0.4 | 2.0 | 0.8 | 0.4 | 0.2 | .... | .... | .... | .... | .... | .... | ... |
| 1.2 | 60 | 48 | 539 | 42.0 | 9.2 | 2.8 | 1.1 | 0.5 | 0.3 | 0.2 | .... | .... | .... | .... | ... | ... |
| 1.4 | 70 | 56 | 628 | 56.0 | 12.5 | 3.9 | 1.5 | 0.7 | 0.5 | 0.3 | .... | .... | .... | .... | .... | ... |
| 1.6 | 80 | 64 | 718 | 74.0 | 16.3 | 5.1 | 2.0 | 0.8 | 0.6 | 0.4 | 0.2 | .... | .... | .... | .... | ... |
| 1.8 | 90 | 72 | 808 | 93.0 | 20.7 | 6.5 | 2.4 | 1.1 | 0.8 | 0.5 | 0.3 | .... | .... | .... | .... | ... |
| 2.0 | 100 | 80 | 898 | 115.0 | 25.4 | 8.0 | 3.0 | 1.4 | 0.9 | 0.7 | 0.4 | 0.2 | .... | .... | .... | ... |
| 2.2 | 110 | 88 | 987 | 140.0 | 30.8 | 9.5 | 3.7 | 1.6 | 1.1 | 0.8 | 0.4 | 0.3 | .... | .... | .... | ... |
| 2.4 | 120 | 96 | 1,077 | 165.0 | 36.5 | 11.4 | 4.4 | 1.9 | 1.3 | 1.0 | 0.5 | 0.3 | 0.2 | .... | .... | ... |
| 2.6 | 130 | 104 | 1,167 | ..... | 43.0 | 13.3 | 5.1 | 2.3 | 1.6 | 1.1 | 0.6 | 0.4 | 0.3 | .... | .... | ... |
| 2.8 | 140 | 112 | 1,257 | ..... | 50.0 | 15.5 | 5.9 | 2.6 | 1.8 | 1.3 | 0.7 | 0.4 | 0.3 | .... | .... | ... |
| 3.0 | 150 | 120 | 1,346 | ..... | 57.3 | 17.8 | 6.8 | 3.0 | 2.1 | 1.5 | 0.8 | 0.5 | 0.4 | 0.2 | .... | ... |

* From Scobey *et al.* (1920).

[a] Customary or southern California miner's inch = 1/50 cu. ft. per sec.

[b] Statute inch = 1/40 cu. ft. per sec.

Computed by Scobey's formula: $H = \dfrac{33{,}610\, Q^2}{C_s^2 d^{5.25}}$, where $Q$ = flow in cubic feet per second; $C_s$ = 0.310; $d$ = diameter in inches; and $H$ = friction loss in feet per 1,000 feet.

persists for several weeks. The effect of this process on citrus trees is generally detrimental.

In order to make subirrigation from ditches practicable, at least three conditions must exist, namely, a substratum of low permeability, a porous surface soil favorable to lateral movement of soil moisture, and facilities for drainage. As these three conditions seldom exist simultaneously, the areas adapted to this method of irrigation are limited. Where these conditions do exist, there will probably still be a danger of developing an uncontrolled drainage problem during periods of high rainfall.

Subirrigation by means of a system of porous or open-jointed pipes is sometimes practiced. Many advantages have been claimed for this system, including economy in the use of water, decrease in cultivation costs, practical elimination of evaporation losses from the soil surface, and elimination of soil erosion by irrigation. Since, in permeable soils, water passes downward with comparatively small lateral percolation, adequate irrigation under these conditions requires a close spacing of the subirrigation lines, making the cost of this system very high.

## SURFACE IRRIGATION

Surface irrigation includes all methods by which the surface of the soil is used to convey the water, such as the following.

*Border method.*—This method employs a series of parallel levees extending through the orchard, the areas between levees being flooded in the process of irrigation. To build the levees an orchard ridger, or a double-disk harrow with disks set to face inward, is commonly used. The ridges or levees may be left throughout the season or may be constructed before and torn down after each irrigation. In general, the method is adapted to coarse-textured soils on relatively flat slopes. It is not suited to the use of small flows of water. Where a sufficiently large flow of water is available, compensation for changes in grade may be effected by varying the flow delivered to different borders.

In preparing land for border irrigation it is not necessary to make a uniform slope through the entire length of run, so long as the grade in the different sections is kept within established limits. However, it is essential that there be very little cross slope across the borders.

In the irrigation of citrus orchards in California the use of this method has been limited mainly to the irrigation of young trees. The method should not be used where soils remain damp for long periods after irrigation, because there is danger of gummosis infection of the tree trunk.

On the sandy soils[1] of Yuma Mesa in Arizona, Smith, Kinnison, and Carns (1931) report the use of the furrow and the square-basin methods, neither of which is recommended if conditions permit the border or strip method. For newly planted orchards the borders are made about 7 feet wide. As the trees become large and the root system more extensive, the borders are wid-

[1] These sandy soils are reported as varying from coarse to fine, with an average porosity of 39.7 per cent, an apparent specific gravity of 1.54, and an average moisture equivalent in the top five feet of soil of 5.0 per cent.

ened until for a full-bearing grove the full width between the trees is utilized. If large flows of water are available for these soils, a slope of about 0.05 foot per 100 feet is recommended; with smaller flows, a grade of 0.2 foot per 100 feet may be used.

Modifications of this method may be used to meet special conditions. Occasionally where summer cover-crops are raised, levees are made on each side of the tree row along the drip of the tree. These levees form a center border 8 to 10 feet wide in which the cover crop is planted. This permits independent irrigation of cover crops and trees and may be a decided advantage if a water shortage occurs, when the tree rows may be irrigated and the cover crop abandoned.

*Contour checks.*—This method employs a series of irregular basins or strips formed by small levees or ridges on level contours. The contour interval usually ranges from 0.1 to 0.2 foot and requires a flow of water large enough to permit complete flooding of the check without excessive penetration at the entrance end of the check. The method is being used successfully in a limited number of grapefruit orchards in the sandy soils of the Imperial Valley, where rainfall is inadequate to remove excess salines from the soil profile, where the grades of the land are flat, and where the flows of water are comparatively large and delivery is made through ditches under conditions unsuited to furrow irrigation. Because of the danger of gummosis infection resulting from wet soil against the tree trunk this method should be used only on sandy soils and where the trees are on sour orange rootstock. (See chap. ii, p. 104, and chap. xi.) Brown (1933) gives a description of this method as used in deciduous orchards.

*Basin irrigation.*—In the early development of the citrus industry in California this method of irrigation was extensively used. At that time the delivery and distribution of water was mainly through open ditches, the irrigation flows were large in comparison to present-day deliveries, and uniform flow control in furrow irrigation was difficult and uncertain. Changes in methods of water delivery, and widespread gummosis infection, resulted in near-abondonment of this method on all soil types except the coarse-textured ones. However, under careful management it permits high efficiencies in the use of irrigation water and reduction in amount of fertilizer lost by excessive leaching.

Under this type of irrigation the orchard is divided into a series of squares or rectangles by means of levees and cross levees. Conditions of soil type, age of trees, slope of land, and size of irrigation stream determine the size of basin to be used, which ranges from the usual one-tree basin to that serving many trees. Success depends on the choice of a basin of proper size and the construction of a substantial levee system which will hold the desired depth of water. Steel or timber V crowders, numerous types of orchard ridgers, reversible disks, or specially designed disk plows are used in building the levees.

In applying the water, the basin nearest to or farthest from the source of supply may be filled with water first. Where the basin nearest the source of

supply is to be filled first, the levees are built without breaks between the basins. When the first basin has been filled, the levee separating it from the one below is cut and the water is drained from the upper basin into the one next below. When the irrigation of the "tier" has been completed, the lower

Fig. 156. Two views of basin irrigation. (After Smith, Kinnison, and Carns, 1931. Courtesy of the Arizona Agricultural Experiment Station.)

basins are left filled or partly filled with water, with but little standing water in the upper ones. This method of cutting from one basin to another is used only on coarse-textured soils with flat grades. When the lower basin is irrigated first, an opening is left in the levees separating the basins, the water being allowed to run through to the lower basin. When this has been filled to the desired depth, the opening is closed and the one above is filled. (See fig. 156.)

A more desirable way, especially useful as a means of applying uniformly shallow depths of water to coarse-textured soils, is to construct a temporary ditch between alternate tiers and deliver water directly to each basin. Occasionally, portable slip-joint pipe or canvas hose is used for direct delivery of water from the pipe line to the tree basins.

Where the slope is such that a single basin for each tree will not permit an even distribution of water, the area surrounding each tree may be divided into four basins, or a single basin may be built on the upper side of the tree. However, this construction is generally impractical and furrow irrigation is usually resorted to when soil and topographical conditions demand its use.

Mulched-basin irrigation consists in the building of permanent basins with substantial levees and applying to each basin, as a soil covering, a mulch of organic material such as barnyard manure, bean straw, or alfalfa hay. Water is delivered to each basin from a ditch so placed as to separate the adjacent tiers. From observation, Briggs, Jensen, and McLane (1917) reported favorable results from the use of this method as a means of soil-moisture conservation and as an aid in the control of mottle-leaf. Later observations failed to substantiate these conclusions and the method has practically been abandoned because of potential tree injury from fire and rodents.

The principal advantage of the basin system of irrigation is that, under favorable conditions of topography, a uniform depth of water may be applied over the entire soil surface, resulting in uniform penetration and the moistening of the soil to any desired depth. Under conditions to which this system is adapted, the cost of land preparation is not excessive and larger irrigation streams can be handled at a low labor cost. Field observations have shown, however, that if it is in use over a period of years, especially on fine-textured soils, there is a high incidence of gummosis where the soil in contact with the tree trunk has been irrigated. The continuous attention which the method requires makes it generally impractical for night irrigation.

*Furrow irrigation.*—The irrigation of citrus orchards by means of furrows is the method most extensively used and covers a wide range in soil type and topography. It permits the use of small flows of water, and the direction of the furrows can be readily changed to fit the changing topography of the land. On soils of low permeability, the application of water may be continued with a minimum of attention until the desired degree of penetration has been obtained. Conditions unfavorable to its use are steep slopes, where erosion is excessive, and flat grades with very porous soils. However, no matter how uniform the grade nor how much care is taken in regulation of the flow, it must be borne in mind that it is not possible to obtain uniform penetration in depth and lateral spread throughout the length of the run. Numerous excavations in varying soil types under different periods of water application have shown a wide variation in soil-moisture patterns. An example of the variation that may be found in adjacent furrows under similar conditions of water application is shown in figure 157. Seldom is all the soil in the root zone moistened when the furrow method is used. Soil characteristics, number and spacing of furrows, and period of application are the principal factors which

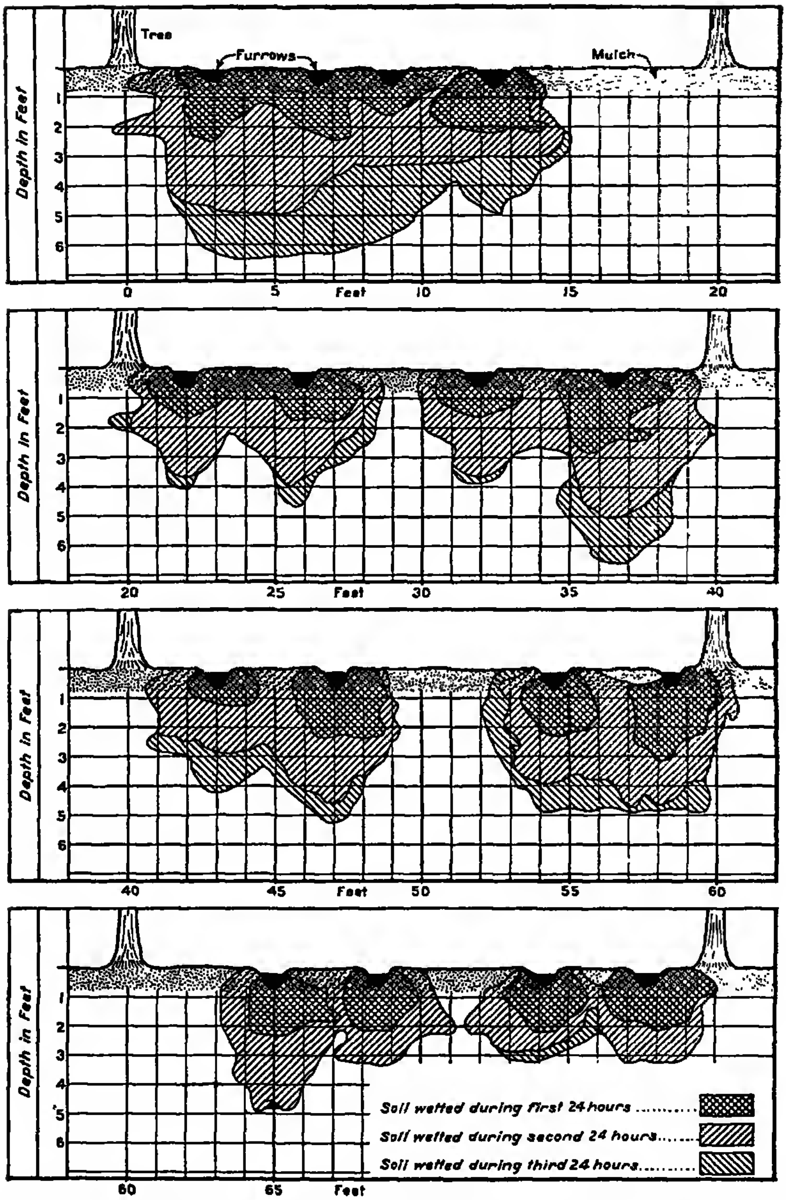


Fig. 157. Distribution of water from sixteen consecutive furrows, showing daily progress of saturation of a sandy loam soil near Riverside, California. (Courtesy of the U. S. Department of Agriculture.)

govern the amount of soil wet. Curved furrows, cross furrows, and zigzag furrows are some of the means used for moistening a greater portion of the soil.

In recent years the broad-furrow and the compacted-furrow methods have been used by citrus growers. A broad flat furrow permits the wetting of a larger soil-surface area than is accomplished by use of the ordinary V-shaped furrow; and on relatively level land, when the furrows are carefully made, good results are obtained. Taylor (1941) describes the method and the equipment used in making broad furrows. On shallow soils, or on very permeable soils, where excessive penetration would occur should ordinary furrows or very long furrows be used, the compacted furrow is sometimes employed. The soil in the furrows is compacted by weighted wheels attached just behind the furrowing attachments, or by torpedo-shaped weights which, when pulled behind the furrowing shovels through the loose soil, compact the walls and bottom of the furrows. Smooth and compacted furrows thus made take water more slowly than furrows that are rough and loose.

The number of furrows used per tree row depends primarily upon the soil characteristics, tree size, row spacing, and width of furrow. Where trees are small and have a root system occupying only a small part of the soil, a single furrow may be used to advantage. As the size of the trees increases, the number of furrows is increased until the entire space between tree rows is irrigated. Usually the branches of the trees force the furrowing machine away from the tree row, and where straight furrows are used in mature groves an unirrigated strip 6 to 12 feet wide is often found along the tree rows paralleling the furrows. Special furrowing devices are sometimes used which make it possible to place the furrows beneath the trees.

In porous soils on rather flat grades it is advisable not to have the furrows exceed 220 feet in length. As the grade increases, or the soils become heavier, the length may be increased. In heavy soils which take water slowly a length of 660 feet is occasionally used. Uniformity in moisture penetration usually decreases with increase in the length of run, and runs in excess of 330 feet should normally be avoided.

Furrow irrigation is used under wide variations in grade, from 0.1 foot per 100 feet on flat valley land to 5 feet or more per 100 feet on the steeper hillsides. In medium soil types such as the loams and sandy loams a desirable grade is from 3 to 6 inches per 100 feet. In the coarse-textured soils this grade can be increased to the limit under which the soil will stand without erosion. In the fine-textured soils which take water slowly it may be necessary to hold water in the furrows for periods of 72 hours or more. Unless a substantial grade is available, a delicate adjustment of the flow is required if the furrows are to be kept from filling and breaking over. Entry of water into soils varies widely among soils and often within the same soil types which have been subjected to different cultural practices. The grades just discussed are, therefore, for general conditions only. Practical experience will determine the best grades for furrows to suit local conditions.

No rules governing correct spacing of furrows can be laid down, since each decision must rest upon observation of the particular soil to which water is

being applied. In coarse-textured soils water has a tendency to pass downward with but little lateral movement. If it meets with finer-textured subsoil, or hardpan, the rate of its movement is retarded, and increased lateral movement occurs. Under these conditions, the soil immediately above the restricting layer is nearly or completely saturated—a condition which is often referred to as "perched" water table and is not favorable to the development of citrus-tree roots.

Furrows should be deep enough to carry their allotted stream without danger of breaks. On the flat lands and in light soils where large streams are needed they should obviously be deeper than on steeper slopes where small streams are used. In a soil of uniform texture and structure there is no particular advantage in the use of deep furrows over shallow furrows in obtaining satisfactory depth of penetration.

Cultivating the bottoms of furrows might increase the rate of water infiltrations. However, the benefits seldom extend beyond the first irrigation, especially if the soils have a tendency to "run together" when the water is applied. (For a discussion of the subject of water penetration in dispersed soils see chap. iv, p. 234.)

*Irrigation by sprinkling.*—Within the last decade there has been a very large increase in the orchard area irrigated by sprinklers, undoubtedly resulting from improvement in sprinkler equipment as well as from improvement in irrigation technique. The systems used in the early development of sprinkling had sprinklers mounted on risers which extended above the trees, but this arrangement has, in the main, given way to portable sprinklers on stationary pipe systems, or to sprinklers mounted on portable pipe or hose—systems which, particularly the latter, are cheaper and are more adaptable to orchard irrigation needs than the one earlier in use. The per-acre installation costs might range from $300 for the fixed type to as little as $50 for the portable. The cost of irrigation labor under the fixed-type system is usually lower than for the other.

Sprinkler irrigation is finding relatively wide use on steep slopes and on shallow claypan soils where it is especially necessary to prevent excessive amounts of moisture from accumulating in the subsoil. Generally speaking, the sprinkler system is used where other methods are not adaptable.

The design of a sprinkler system is properly the work of an engineer and should not be attempted by anyone not familiar with hydraulics. A few of the published papers that give information on the use of sprinkler irrigation systems and their design are given by Staebner (1931) and Christiansen (1942).

## WATER SUPPLY

The development of water supplies for citrus irrigation is normally a coöperative enterprise, as the undertaking is usually beyond the resources or abilities of any one man to develop. Such irrigation agencies as mutual water companies, irrigation districts, and reclamation projects have all played a part in developing water supplies. Where surface-water supplies can be easily developed, and where a ground water is available at a reason-

able pumping lift, many owners have their own water supply. Adams (1929) has described the irrigation districts of California, and Hutchins (1936) describes coöperative irrigation company organization and operation.

*Water quality.*—A good water supply must not only be adequate to meet the demand on a quantitative basis; it must also be of good quality. The water in mountain streams is normally very low in salt content; but as the stream passes through alluvial areas, receiving drainage water from irrigated lands, the salt content increases until the water may not be satisfactory

TABLE 43

SALT CONTENT OF THE SANTA ANA RIVER AT SUCCESSIVE DOWNSTREAM STAGES*

| Stage | Electrical conductivity $K \times 10^6$ at 25° C. | Boron, p.p.m. | Sodium, per cent | Milligram equivalents per liter[a] | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Bicarbonate ($HCO_3$) | Chloride (Cl) | Sulfate ($SO_4$) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) |
| Mouth of upper canyon...... | 24.8 | 0.06 | 29 | 2.05 | 0.11 | 0.38 | 1.30 | 0.57 | 0.78 |
| Bunker Hill dike, Colton.... | 34.6 | 0.06 | 20 | 2.81 | 0.25 | 0.71 | 2.05 | 0.90 | 0.74 |
| Riverside Narrows....... | 72.9 | 0.13 | 32 | 4.44 | 1.75 | 1.10 | 3.80 | 1.39 | 2.43 |
| Lower canyon at county line.. | 82.7 | 0.15 | 30 | 4.95 | 2.11 | 1.83 | 4.45 | 2.05 | 2.74 |
| New Hope drain below Santa Ana........ ...... | 168.0 | 0.34 | 40 | 7.70 | 4.90 | 5.52 | 7.20 | 4.18 | 7.61 |

* Data from C. S. Scofield, Quality of Irrigation Water, State of California Department of Public Works, Division of Water Resources, Bull. No. 40, 1933.

[a] To compare data on chloride in this table with those in table 44, multiply milligram equivalents per liter by 35.5 to convert to parts per million.

for irrigation. The Santa Ana River, California, provides a good example of this condition. (See table 43.) Quality is judged not alone by the total saline content, but by the character and relative proportions of the saline constituents as well. Water containing a high percentage of sodium in proportion to its calcium and magnesium content might produce, in some soils, an undesirable effect on soil structure and soil reaction. In fact, in altering the soil structure, it might so retard the infiltration of water that excess salines would not be leached from the soil occupied by roots. The nature of the soil, drainage conditions, climate, and relative proportions of the ions present determine, in large measure, whether water can be used safely for irrigation. During periods of drought, water more saline than is normally considered safe may be used for short periods, as in the Imperial Valley in 1934, when water with a saline content in excess of 2,000 parts per million was used to irrigate grapefruit orchards. Fortunately, both the soil and the water had a high calcium content. As will be shown later, it is advisable to maintain a high soil-moisture percentage when using water of high salt content.

Citrus trees have a very low tolerance to boron. Eaton (1935) reports boron injury to lemon trees in areas of low rainfall where irrigation water containing 0.5 p.p.m. had been used.

While no universal standards have been approved for judging the quality of irrigation water for citrus, the evaluation compiled by Chapman from a

number of sources (see table 44) can be considered a safe guide. (See also Vol. I, chap. vii, p. 757, and this volume, chap. iv, p. 247.)

*Water costs.*—In arid sections, irrigation costs represent an important part of the total cost of producing citrus fruit. Adams and Huberty (1933) reported on water cost, exclusive of irrigating labor, on about 900 orchards in the south coastal basin of southern California. Two-thirds of the orange growers were spending more than $18 per acre per annum for water; two-thirds of the lemon growers, more than $24.

TABLE 44

STANDARDS FOR IRRIGATION WATER

| Rating of water | $K \times 10^5$ at 25° C.[a] | Per cent sodium $\frac{Na \times 100}{Ca+Mg+Na}$[b] | Chloride, p.p.m. | Boron, p.p.m. |
|---|---|---|---|---|
| Suitable under most conditions. | Less than 75 | Less than 60 | Less than 75 | Less than 0.5 |
| Suitability dependent upon soil, crop, climatic, and other factors | 75–300 | 60–70 | 75–245 | 0.5–2.0 |
| Unsuitable under most conditions | 300+ | 70+ | 245+ | 2.0+ |

[a] Specific electrical conductance in reciprocal ohms at 25° C. multiplied by $10^5$. This is a fairly accurate index of the total concentration of salts in a water; multiplied by 7, it gives the approximate total of dissolved solids in parts per million (p.p.m.).
[b] Concentrations expressed as milligram equivalents (M.E.) per liter are used in this computation.

*Irrigation labor requirements.*—The labor required for irrigating varies widely, from a few hours' time per acre per annum on the heavy soils of the coastal area to as much as 25 hours per acre in the desert areas.

## THE SOIL-MOISTURE SYSTEM

The thin crust of the earth's surface, composed of disintegrated and weathered rock plus accumulated organic material, makes up what we know as the soil. It is a three-phase system consisting of solids, liquids, and gases. Between the solid particles is the pore space which is occupied by the liquid and gaseous phases. As the amount of soil water is varied, the volume of soil air is changed, and when a soil is saturated, little or no air is present in the soil. The practice of irrigation, therefore, not only affects soil moisture, but also has an important influence on the soil atmosphere.

Particles ranging in magnitude from ultramicroscopic to gravel size make up the solid phase. Finely divided particles have a large surface area, and the angles of contact between particles are very acute. The size and shape of soil particles, therefore, bear a very important relationship to the water-holding capacity of soils, for it is on the surface of the soil particle and at the interfaces that water is stored.

Practically from the beginning of the study of soil physics, investigators have been interested in the response of plants to changes in soil moisture and to the energy values represented at various soil-moisture contents. As there is not yet a universally accepted nomenclature of soil physics, the present

text uses some terms on which there is not universal agreement. However, for want of better terminology to describe field conditions, the terms in common usage have been adhered to.

## SOIL-MOISTURE TERMINOLOGY

*Moisture content.*—Soil moisture is normally expressed as a percentage of the weight of water to the oven-dry weight of soil. If a sample of soil were weighed, thoroughly oven-dried, and then reweighed, the weight of water lost could be determined. This loss divided by the dry weight of soil and multiplied by 100 gives the moisture percentage of the original sample. As the weights of unit volumes of dry soils vary widely, the amount of water represented by a given percentage varies widely. An expression of the water content by volume would be more satisfactory.

*Apparent specific gravity (volume weight).*—To convert moisture percentage to equivalent depth of water, it is necessary to know the apparent density of the soil—the weight per unit volume of soil in place. For convenience in this conversion it is well to establish a ratio between the weight of a unit of soil in place to the weight of a similar unit of water. This is referred to as apparent specific gravity, or volume weight. While this ratio, for noncompacted soils, normally varies from about 1.2 for clay soils to about 1.4 for sands, the extremes are greater than this. Curry (1931) has listed several methods that are used in determining the volume weight of soils.

*Hygroscopic coefficient.*—Hygroscopic coefficient is a term used to designate the amount of water a soil will absorb from an atmosphere of water vapor of known physical condition. The term hygroscopic moisture has been used loosely to designate the amount of water a soil will collect on the surface of the particle when the soil is exposed to the atmosphere. As the atmospheric conditions are not constant, the soil-moisture content varies. However, for soils exposed to similar atmospheric conditions, variation in hygroscopic moisture is a rough measure of the variations of surface activity and indirectly an indication of the colloidal content of the soil (Robinson, 1922).

*Field capacity, normal moisture capacity.*—Both these terms are used to describe the moisture content of a freely drained soil several days after irrigation (Shaw, 1927, and Veihmeyer, 1927). They represent a soil-moisture content at which downward movement of water has practically ceased. Depth of soil wet, depth to water table, and other factors can affect field capacity; yet it represents, under normal irrigation practice, a fairly consistent moisture condition.

*Moisture equivalent.*—This term was introduced by Briggs and McLane (1907) to represent the amount of water, expressed as a percentage of oven-dry weight, retained in a soil which had been saturated and subjected for a specific time to centrifuging at an acceleration of 1,000 gravity. The moisture-equivalent values for soils in the range of sandy loams to silt loams agree very closely with the field capacity of those soils, whereas in coarse-textured soils the moisture-equivalent values are lower than field capacity (Veihmeyer and Hendrickson, 1931).

*Wilting point, permanent wilting percentage.*—The first of these two terms was used by Briggs and Shantz (1912) to describe the soil-moisture content at which plants would lose turgor and would remain wilted until water was applied to the soil. Their investigations indicated that all plants reduce the soil moisture to the same relative percentage when wilting occurs. They concluded that a value equivalent to the wilting point could be determined from the moisture equivalent by dividing it by the factor 1.84. The value obtained they called the wilting coefficient.

The wilting coefficient was widely used until Veihmeyer and Hendrickson (1928) showed that the ratio between the moisture equivalent and the wilting coefficient was not a constant. Instead of the ratio 1.84, they found the range to be from 1.3 to more than 4. Since soil investigators had long been calculating the wilting-point values, and since these indicated a point on the soil-moisture curve, they proposed the term permanent wilting percentage—a ratio to be determined from plants growing in the soil.

Furr and Taylor (1939) and Furr and Reeve (1945) use the term wilting range. The determination is made by observing the responses of sunflower plants to soil-moisture conditions. It represents the range in moisture content from the permanent wilt of basal leaves to complete wilt of all leaves on the plant.

*Infiltration.*—Infiltration refers to the rate per unit of time at which water enters a soil when there is standing water on the soil surface. The farmer is interested not only in the rate at which water enters an irrigated soil, but also in infiltration rates as they affect the recharge of ground-water basins by natural or artificial means.

The problem of obtaining desirable water penetration in citrus orchards is often a serious one, especially on soils that compact easily (Huberty, 1945), and where soil structure has been destroyed by fertilizer practices or irrigation water with a high sodium percentage (Huberty and Pillsbury, 1941, and Aldrich, Parker, and Chapman, 1945).

Large and long-continued applications of fertilizers containing sodium on soils irrigated with water of low calcium content produce an undesirable soil structure resulting in lowered infiltration rates. Also, large applications of ammonium sulphate, especially on the medium-textured soils, can markedly reduce infiltration rates. The effect of the latter fertilizer is to acidify the soil until the nitrifying organisms of the soil cannot function satisfactorily and the ammonium ion remains on the surface of the clay particles. When this occurs, the crumb structure of the soil is destroyed and the rate at which water enters the soil is reduced.

The acidifying effect of ammonium sulphate and the high degree of ammonium fixed on the clay fraction of the soil are clearly shown in results obtained at the Citrus Experiment Station, Riverside (Huberty and Haas, 1940). The pH values obtained in 1938 on 1 to 5 soil-water suspensions on samples taken to a depth of 2 feet are as follows: at surface, 5.0; at 0.3 ft., 4.9; at 0.5 ft., 4.9; at 0.9 ft., 5.4; and at 2 ft., 7.2. Under these acid conditions ammonium made up a good portion of the fixed bases of the soil.

Applications of organic matter to semiarid and arid soils normally result in improved soil structure and hence an increase in rate of water penetration.

Improvement in soil structure through aggregation can at times be accomplished by allowing the soil to dry. At and near the surface this can be accomplished by evaporation, but at lower depths plants are necessary to extract the moisture.

## SOIL-MOISTURE STORAGE AND MOVEMENT

A common method of classifying soil moisture is that of Briggs (1897). He assumed three kinds of soil moisture, namely: hygroscopic, or water which is absorbed from the atmosphere and held by adhesion to the surface of the soil particles; capillary, or water held by surface tension; and gravitational, or water which would move out under free drainage conditions. This concept of soil moisture assumes definite boundaries between the types of moisture indicated. Measurements made in the moisture range from field capacity to the wilting percentage show no discontinuity in the curve representing the relationship between soil-moisture content and the energy required per unit mass to remove water from the soil to a place of reference.

Buckingham (1907) was among the first to attempt to measure the energy required to remove moisture from soil. He originated the term capillary potential to define the value which measures, at any given point, the attraction of soil for water. Other investigators include Shull (1916), Thomas (1921), Edlefsen (1934), Edlefsen and Anderson (1943), Schofield (1935), and Richards and Weaver (1944). The results obtained on nonsaline soils show that in the moisture range between field capacity and the wilting point the change in force required to remove water from the soil is very gradual until the wilting point is reached, when there is an abrupt change. At field capacity, the data available indicate that water is held with a force of from 0.2 to 0.3 of an atmosphere; at the wilting percentage, with a force of about 15 atmospheres. Figure 158 presents the results obtained by Shull (1916) with the seed-absorption method on a silt loam soil and on a coarse sand. The abrupt changes in the curves represent the soil-moisture conditions when plants wilt. Results obtained by Edlefsen (1934) on a fine-textured soil, a coarse soil, and on a mixture of the two, are shown in figure 159. The similarity in shape of the curves obtained by the two investigators is pronounced.

To the surface forces mentioned above should be added the osmotic concentration of the soil solution (Edlefsen and Anderson, 1943). Because of the high osmotic values of saline soil solutions the moisture content should be kept higher for conditions favorable to plant growth in saline than in nonsaline soils (Magistad and Reitemeier, 1943, and Wadleigh, 1946).

The amount of available water that can be stored in soils of the same general texture may vary considerably, as has already been remarked. Actual results obtained on four soils in southern California on which citrus is growing are, however, as presented below. Although there are exceptions, the results show generally the changes in volume of soil atmosphere and the influence of particle size on the water-holding properties of soil.

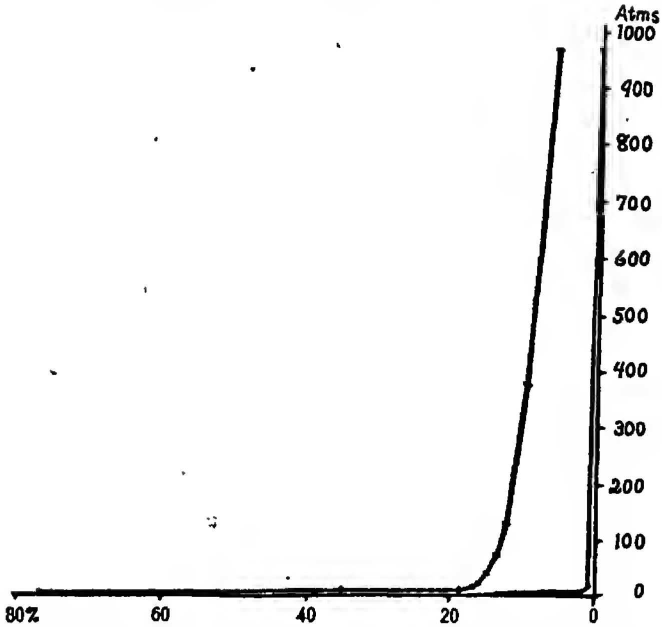


Fig. 158. Curves showing increase in the surface forces of soils as drying proceeds; to the left, for subsoil of the Oswego silt loam; to the right, for no. 2/0 sand. (After Shull, 1916.)

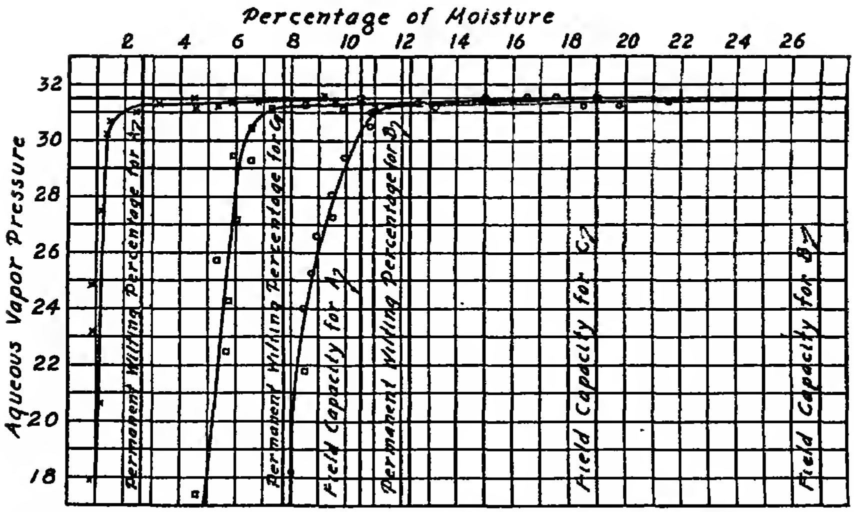


Fig. 159. Aqueous-vapor pressure curves, permanent wilting percentages, and field capacities for a fine sandy loam, *A*, on the left; a clay loam, *B*, on the right; and a half-and-half mixture, *C*, in the center. (After Edlefsen, 1934.)

For both the sand and the sandy loam, fluctuations in the moisture content between field capacity and wilting percentage do not materially alter the volume of soil air. With the clay loam soil listed, the air volume increased 125 per cent through this moisture range. To permit wide fluctuations in the volume of air and water in the soil, some orchardists practice what is known as alternate irrigation. By this method the soil on one side of the trees only is wetted at any one irrigation.

Soil-moisture movement in the liquid phase is dependent upon two forces, gravity and capillarity. When moisture is present in excess of field capacity, gravity is the dominant force and the movement is through the large pore spaces; when moisture is below field capacity, capillary forces are dominant.

WATER DATA: RESULTS ON FOUR SOILS

| Factor | Hanford sand | | Ramona sandy loam | | Yolo loam | | Dublin clay loam | |
|---|---|---|---|---|---|---|---|---|
| Field capacity (per cent) | 7.6 | | 12.0 | | 22.5 | | 29.7 | |
| Wilting percentage (per cent) | 3.0 | | 4.5 | | 12.0 | | 13.2 | |
| | F.c. | w.p. | F.c. | w.p. | F.c. | w.p. | F.c. | w.p. |
| Volume of solid phase | 60 | 60 | 56 | 56 | 49 | 49 | 47 | 47 |
| Volume of liquid phase | 12 | 5 | 18 | 7 | 29 | 16 | 37 | 17 |
| Volume of gaseous phase | 28 | 35 | 26 | 37 | 22 | 35 | 16 | 36 |
| Depth of water available per foot of soil (inches) | 0.9 | | 1.3 | | 1.0 | | 2.5 | |

F.c.—at field capacity; w.p.—wilting percentage.

Numerous measurements have been made on the rate of capillary movement from a free water surface (Harris and Turpin, 1917; McLaughlin, 1920; Veihmeyer, 1927; Lewis, 1937). The rate of rise in sand is rapid but is usually limited to less than one foot; in fine-textured soil it is very slow but more extensive. Movement of moisture from a moist soil to a dry soil is slow and limited (Veihmeyer, 1927). Veihmeyer's studies showed that cultivation of irrigated soils free of a water table did not, *per se*, conserve water. (See chap. vi, above.)

At low soil-moisture content, water movement is in the vapor phase. Variation in the temperature or moisture content of the soil may change the vapor pressure of the soil atmosphere, and this in turn will cause a movement of vapor from a region of high pressure to one of lower value. The amount of water transferred in the vapor phase by soils in the citrus-growing areas is doubtless very small.

## RESPONSE OF CITRUS TO IRRIGATION

*Water requirement of citrus.*—Efficient irrigation practice is dependent upon a sensible application of the physics of soil moisture and an understanding of the use of water by plants. When water is applied to the surface of a soil in the orchard, it moves downward, through the action of gravity and capillarity. The rate of movement depends mainly upon the relative size

of the pores in the soil. If the soil being irrigated is deep and well drained, the degree of moisture content known as field capacity will be attained in a few days after irrigation if the soil texture is coarse and in four or five days if it is fine. If the soil is relatively uniform in texture and structure throughout the area wetted, the distribution of moisture will be relatively uniform. When there is a soil stratum of low permeability, water movement downward is restricted, and if more water is applied than is required to bring to field capacity the soil that is above the compact layer, a saturated soil condition will result (Huberty and Pillsbury, 1943). This produces a soil environment poorly adapted to citrus trees. Many citrus orchards have declined as a result of excess soil moisture, a condition often called "overirrigation"—which implies that irrigation alone, and not rainfall, is often the source of the excess moisture. In orchards on shallow claypan soils with a sod covering the danger of excessive moisture is especially great in winter. Investigators at the Arizona Agricultural Experiment Station have demonstrated that high soil moisture in combination with a high-lime soil is especially conducive to chlorosis in citrus (Burgess and Pohlman, 1928). Pathology of tree decline is discussed in the next chapter.

Unlike deciduous trees, citrus trees may transpire relatively large amounts of water in the period from late fall to early spring. Water must be supplied accordingly; and if cover crops and intercrops are grown, moisture must be available in quantities sufficient to meet their needs as well. In young orchards where heavy winter cover crops are produced, the water requirement during the winter months may equal or even exceed the summer irrigation needs of clean-cultivated young orchards. In mature orchards lighter cover crops are usually produced, and with the increased summer needs of the older trees the ratio between the winter and summer water requirements becomes less.

In recent years the practice of noncultivation has become popular in certain sections of the citrus-growing sections of southern California. Weed growth is controlled by spraying with oil or other toxic compounds, or by hoeing, or both.

So far as irrigation is concerned, the system seems to work well on those soils which, under cultivation, develop dense cultivation pans that retard water penetration. For a complete evaluation of the noncultivation system, further study is needed.

The transpirational use of water by citrus trees and the resulting seasonal and yearly irrigation needs are dependent upon several factors, including the size and vigor of the trees, the closeness of planting, and the climatic conditions under which they are grown. (Transpiration is the water used by the crop, and does not include evaporation from the soil mulch, or water loss through runoff or deep percolation.) While soil type influences the required frequency of irrigation and the depth of water to be applied at each irrigation, there is no evidence, other things being equal, that the trees will transpire more water when grown on one soil type than when grown on another.

It has been observed that the seasonal amounts of water applied are often influenced by the availability and cost of the water rather than by the actual irrigation need. Under conditions of low cost, water may be used extravagantly, and as the supply is diminished or the cost increased, the seasonal use becomes less.

Records are available that show the quantities of water delivered by various agencies supplying water for irrigation in the different citrus areas of southern California; but although they are reliable as permanent records of deliveries, they are not necessarily a true indication of the real water requirements of the trees.

TABLE 45

AVERAGE MEAN MONTHLY AUGUST TEMPERATURES (1917–1921) AND AVERAGE ANNUAL RAINFALL OF THE DIFFERENT CLIMATIC ZONES OF SOUTHERN CALIFORNIA*

| Zone | Average mean maximum August temperature | Average annual rainfall |
|---|---|---|
| | *degrees* | *inches* |
| Coastal | 87° F. | 15.6 |
| Intermediate | 91° F. | 19.6 |
| Interior | 94° F. | 16.9 |
| Tulare County (not included above) | 98° F. | 9.96 |

* Data from California Agric. Exper. Sta. Bull. 374, 1924.

For comparison of seasonal depths of water applied in the different localities, the citrus-producing areas of California have been somewhat arbitrarily divided into three groups, namely, the coastal, intermediate, and interior areas (Vaile, 1924). The mean monthly maximum August temperature over a five-year period was used as a zone index, and the average annual rainfall records for seven stations within each zone, covering periods of from twenty-five to forty years, were taken into account. The average mean maximum temperatures of all stations and the average annual rainfall for each zone are shown in table 45.

Recent plantings in the Coachella and Imperial valleys in California and the areas adjacent to Yuma, Arizona, might justify the addition of a fourth group, the desert area. The mean August maximum temperature at Indio in the Coachella Valley is 105°5, and at Yuma, Arizona, 104°1. The average annual rainfall at these stations is 2.89 inches and 3.33 inches, respectively.

The coastal zone includes the coastal plain of San Diego County, most of Orange County, the La Habra and Whittier areas of Los Angeles County, and the coastal plain of Ventura and Santa Barbara counties. The intermediate zone includes the El Cajon, Escondido, and Fallbrook areas of San Diego County, the San Gabriel and Pomona valleys of Los Angeles County, and in Ventura County the area from Saticoy to Fillmore in the Santa Clara River valley. The interior areas would include the Santa Clara River valley east of Fillmore, the San Fernando Valley, the Riverside, San Bernardino, Red-

lands, and Highland districts, and the citrus areas of Tulare, Butte, and Sacramento counties.

Vaile (1924) compared the effect of increasing amounts of irrigation water on yields in the coastal, intermediate, and interior areas. Five classes of water use were recognized: light, moderate, usual, heavy, and very heavy. The most common usage was classed as usual. The designation of class in irrigation and the average yields in each of the climatic zones are given in table 46.

In discussing these results, Vaile concluded: "In the coastal zone a little less than the amount of water now commonly used gives the greatest yields. There is considerable evidence of injury from excessive irrigation throughout this zone, particularly on the heavy soil. In each of the other zones the average yields increase with the use of more water until nearly 50 per cent more than the usual amount is applied. Even in these zones, however, the effects of excessive irrigation are noted on certain groves that are very heavily irrigated."

TABLE 46

Amounts of Water Applied and Yields of Oranges and Lemons under Different Classes of Irrigation*

| Irrigation (class) | Depths of water applied (inches) | | | Pounds per acre (thousands) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Coastal zone | Intermediate zone | Interior zone | Coastal | | Intermediate | | Interior | |
| | | | | Oranges | Lemons | Oranges | Lemons | Oranges | Lemons |
| Light.... ... | Less than 14 | Less than 16.5 | Less than 19 | 18 9 | 23 9 | 17 5 | 22.7 | 12 3 | 15.1 |
| Moderate... . | 14 to 17.9 | 16.5 to 21.4 | 19 to 24.5 | 20.5 | 26.0 | 18 1 | 23 4 | 14.9 | 18.3 |
| Usual... .... | 18 to 21.9 | 21.5 to 26.4 | 25 to 30.9 | 20.1 | 25 6 | 18.5 | 24.0 | 15.5 | 19.0 |
| Heavy....... | 22 to 25 9 | 26 5 to 31.4 | 31 to 36.9 | 19.9 | 25.5 | 20.6 | 26 8 | 19 1 | 23.4 |
| Very heavy... | 26 and more | 31 5 and more | 37 and more | 19.5 | 24.7 | 22.0 | 28.0 | 17.7 | 21.7 |

* Data from Vaile, California Agric. Exper. Sta. Bull. 374.

Beckett, Blaney, and Taylor (1930), in a series of field experiments in northern San Diego County, determined by intensive soil sampling the transpiration use in a number of citrus orchards during 1926 and 1927. In 1928 and 1929 similar work was carried on near Tustin and Santa Ana in Orange County, and during 1930, 1931, and 1932 in the interior areas of Riverside and San Bernardino counties. These investigations were conducted in small plots within selected citrus orchards. The moisture properties of the soil within the plots were determined, and by a series of soil samplings during the irrigation season a record of soil-moisture changes was obtained.

Soil samples for moisture determinations were obtained by means of a soil tube. The soil mulch was sampled separately. Below the mulch, samples were taken in one-foot sections to a depth of six feet, unless the shallowness of the soil prevented. Soil-sampling locations were established at the beginning of the irrigation season. In the course of the season, samples were taken in the vicinity of each sampling point before and after each irrigation, and often at intervals of two to three weeks between irrigations. From these data it was possible to calculate the moisture changes in the soil.

The difference between the water stored in the root zone and the measured quantity of water applied to the area represents the irrigation efficiency, which is normally expressed as a percentage. Irrigation efficiencies vary widely, depending, among other things, on the topography, the method of irrigation, the soil characteristics, and the skill of the operator. Although efficiencies of 70 per cent are attained by the furrow method, they are usually well below this figure.

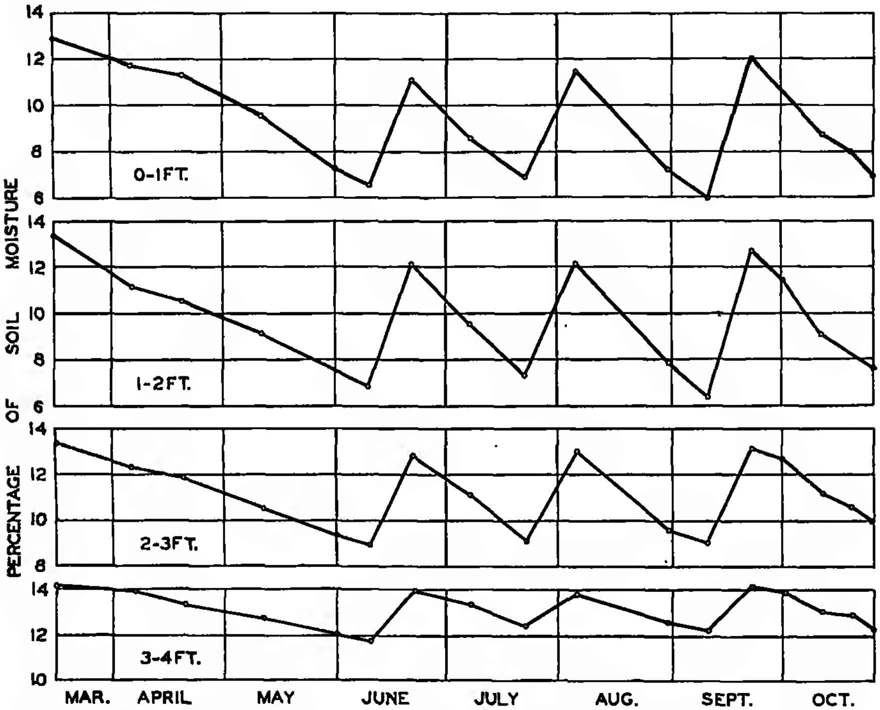


Fig. 160. Seasonal variations in the soil-moisture content in a mature lemon orchard in the intermediate climatic zone of San Diego County, season of 1927. (After Beckett, Blaney, and Taylor, 1930. Courtesy of the California Agricultural Experiment Station.)

An example of the soil-moisture record obtained in a mature Eureka lemon orchard in the intermediate climatic zone of southern California is shown in figure 160. The quantities of water used by this orchard in intervals between irrigations are shown in table 47. Figure 160 shows that in the top two feet of soil the moisture content between irrigations fluctuated through a range of about 7 per cent without an apparent change in the rate of use of water. At no time in the season did the trees in this orchard show evidence of wilting. The range of 7 per cent in moisture is equivalent to an average depth of about 1¼ inches of water per foot for the top two feet of soil. When 2½ inches of moisture had been used from the top two feet, approximately 1 inch had been taken from the third foot, and ½ inch from the fourth foot.

Hence, an average depth of 4 inches of water was available for plant growth within the range of moisture fluctuations.

Under conditions represented by these data, it might be said that if the soil moisture in the first four feet is at field capacity on April 1, the first irrigation will normally not be required until the middle of June. With an average monthly use of 2.5 acre-inches per acre per month during the rest of the summer, the maximum period between irrigations would be 45 to 50 days. On a basis of 60 per cent efficiency in irrigation, a depth of 6 inches of water would be required at each irrigation. Three such irrigations would provide this orchard with adequate moisture well into October.

TABLE 47

QUANTITIES OF WATER USED BY A MATURE LEMON ORCHARD IN THE INTERMEDIATE CLIMATIC ZONE OF SAN DIEGO COUNTY, SEASON OF 1927

| Interval | Number of days | Soil-moisture loss, acre-inches per acre | | | | | |
|---|---|---|---|---|---|---|---|
| | | First foot | Second foot | Third foot | Fourth foot | Total | Equivalent loss in 30 days |
| Mar. 15–May 11 | 57 | 0.93 | 0.66 | 0.57 | 0.36 | 2.52 | 1.33 |
| May 11–June 9 | 29 | 0.55 | 0.40 | 0.29 | 0.18 | 1.42 | 1.47 |
| June 9–July 24 | 45 | 1.00 | 1.14 | 0.93 | 0.42 | 3.49 | 2.33 |
| July 24–Sept. 11 | 49 | 1.37 | 1.37 | 1.03 | 0.45 | 4.22 | 2.58 |
| Sept. 11–Oct. 25 | 44 | 1.23 | 1.17 | 0.83 | 0.52 | 3.75 | 2.55 |
| Mar. 15–Oct. 25 | 224 | 5.08 | 4.74 | 3.65 | 1.93 | 15.40 | .... |

Figures 161 and 162 show the soil-moisture fluctuations and seasonal use of water by a mature navel orange orchard on a sandy loam soil in the interior climatic zone of southern California in 1931. This orchard received six irrigations totaling 30 inches average depth. Transpirational use from April 1 to November 1, as figured from the soil-moisture diagram, shown in figure 162, was 21 inches. The depth of water to be applied by irrigation would normally vary from year to year, depending upon the soil moisture carryover from spring rains and the time at which the first adequate rains occurred in the fall. The total amount of water applied by irrigation was adequate. However, it would have been better to make the May irrigation lighter and the August irrigation heavier, or to have given seven lighter irrigations. The moisture diagram in figure 161 shows that the heavier irrigations of May, June, and July penetrated deeper than 6 feet, which is not necessary when the irrigation water is of high quality.

The dotted line on the graph represents moisture conditions in the unirrigated soil, the upper three feet of which did not reach the permanent wilting percentage until mid-July. The rate of water loss was substantially constant even though the moisture fluctuated in the moistened section.

The average monthly use of water by citrus trees, as determined by Beckett in sixteen orchards in the south coastal basin, has been summarized by Pillsbury, Compton, and Picker (1944). Figure 163, showing the use of

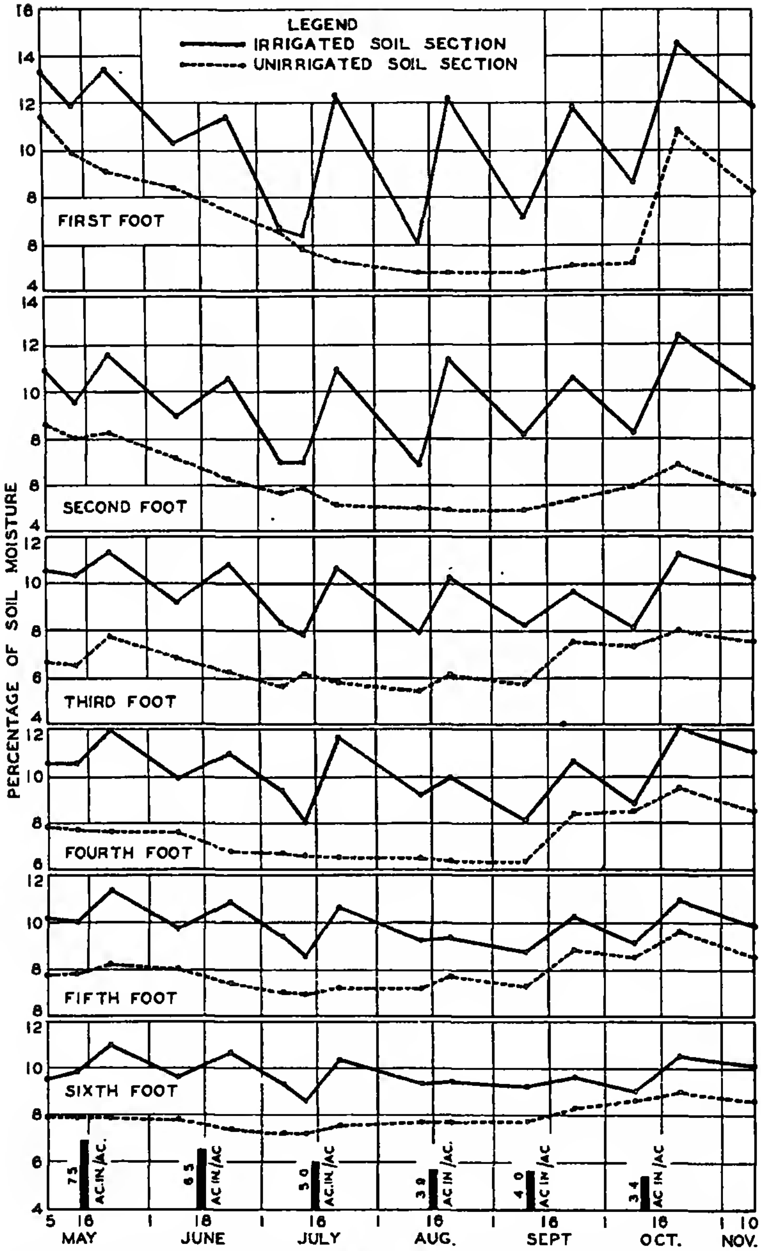


Fig. 161. Seasonal soil-moisture fluctuation in a mature Washington Navel orange orchard in which three irrigations penetrated to a depth below six feet, interior climatic zone of southern California, season of 1931.

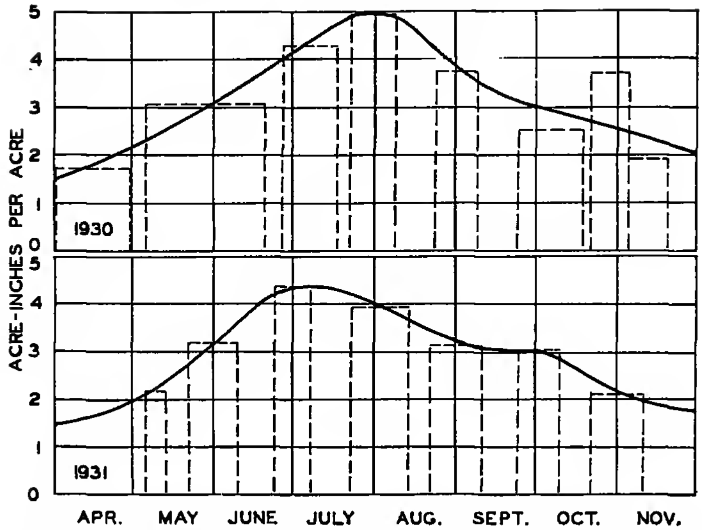


Fig. 162. Seasonal use of water in acre-inches per acre per month in an orchard of mature Washington Navel orange trees in the interior climatic zone of southern California, seasons of 1930 and 1931.

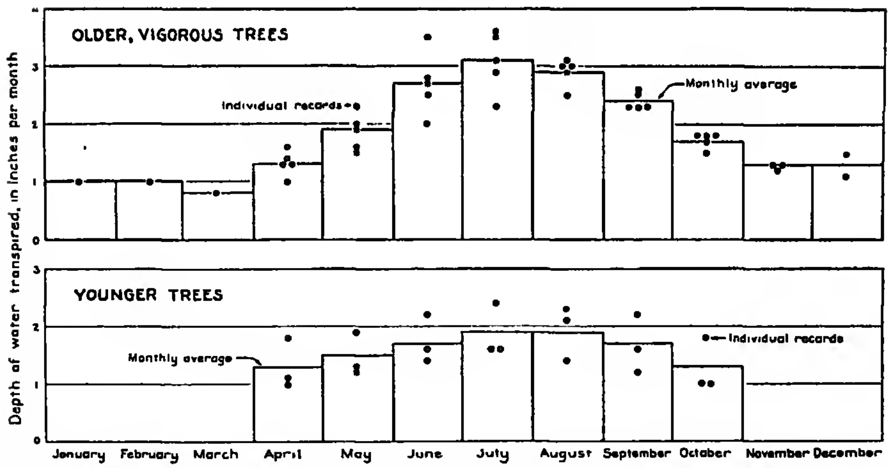


Fig. 163. Distribution of individual monthly, and average monthly, transpiration records, Orange County, 1928–1929. (After Pillsbury, Compton, and Picker, 1944. Courtesy of the California Agricultural Experiment Station.)

water by young and mature citrus trees in Orange County, and figure 164, which illustrates water use by soil depth, have been taken from their publication. The results show the trees to be transpiring at the highest rate during July, and with a total average transpirational use by mature trees of 16 acre-inches per acre in the coastal zones and about 21 inches in the interior area. The

amounts of irrigation water required to meet these transpirational demands are similar to the values listed by Vaile (1924) as common usage.

Observations on water use in an orchard in the interior climatic zone with a heavy summer crop showed transpiration to be about 50 per cent greater for the season than in clean-cultivated orchards. During the period when the cover crop was most vigorous its water use was as great as the tree use.

Measurements made by Pillsbury (1941) in three mature grapefruit groves growing under desert conditions in the Coachella Valley, California, show an

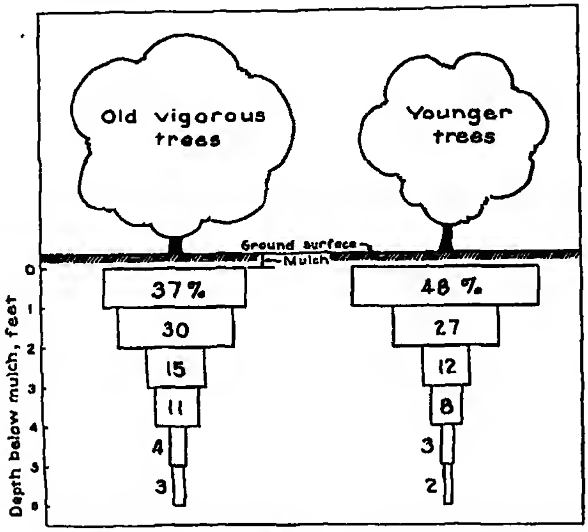


Fig. 164. Loss of moisture by depth, Orange County, 1928–1929. (After Pillsbury, Compton, and Picker, 1944. Courtesy of the California Agricultural Experiment Station.)

average transpiration of about 9 inches a month during July, August, and September, the yearly transpiration use being about 6 feet. To meet this demand requires an average depth of irrigation water of 8 to 9 feet per annum.

Harris, Kinnison, and Albert (1936) report on water use by citrus in the Salt River valley of Arizona, an area characterized by high maximum and mean temperatures, long hot summers and short winters, and with an average annual rainfall of about 7 inches. They conclude that mature Washington Navel orange trees will remove from the soil a little more than 2½ acre-feet of water per acre per annum, and Marsh grapefruit trees will take about 3½ acre-feet. These figures represent the water transpired by the trees and do not include other water losses.

Oppenheimer and Elze (1941), working in the Jaffa district in Palestine, report a seasonal irrigation requirement of mature orange trees of from 800 to 1,000 cubic meters per dunam (equivalent to an average depth of 2¾ feet).

Esselen (1937), reporting on the use of water by Valencia trees on Rough

lemon stock, states that a reduction of the soil moisture to the wilting point in a part of the root zone will result in an increased absorption from the part still containing moisture, under conditions prevailing in the eastern Transvaal in winter.

## EFFECT OF IRRIGATION ON ROOT GROWTH AND ROOT DEVELOPMENT OF CITRUS

That tree roots can be controlled by irrigation has long been contended: frequent light irrigations are supposed to induce shallow rooting, and deep, infrequent irrigations, deep rooting. Except where the moisture has been so high as to produce poor aeration, or where rainfall is inadequate to moisten the soil to normal rooting depths, this hypothesis has not been substantiated under field conditions. At the Citrus Experiment Station, Riverside, plots of Washington Navel orange trees were grown from the third to tenth year under differential irrigation treatments which provided for irrigations on a two, four, and six weeks' schedule. In the course of the winter, when the soil was moist, eight trees were removed from each plot by pulling. No noticeable difference was apparent in the amount, or the pattern, of the roots as affected by the various irrigation treatments, but a very marked difference was shown by type of rootstock; the trees on sour root were very much deeper-rooting than those on sweet root.

The measurement of the rate at which water is lost can be used as an indirect measurement of the concentration of the active roots. Conrad and Veihmeyer (1929) made a study of the rate of moisture loss in relation to the root concentration of grain sorghum and found a high correlation between these two factors.

Shantz (1927), in observing the growth of certain desert plants, concluded that some drought-resistant plants have the ability to extend their roots into dry soil, but that field crops do not. Hendrickson and Veihmeyer (1931) were unable to obtain growth of roots of sunflowers or beans into a soil in which the moisture content was below the permanent wilting percentage.

In the irrigation of citrus by furrows the entire soil mass occupied by the roots is usually not moistened, the unmoistened zones generally representing from 10 to 40 per cent of the total. The unirrigated zones receive rainfall, and where this is adequate to moisten the soil to the depth of normal rooting of the trees it might be expected that a normal root distribution would be found. In these zones root development should continue, elongation of the root system ceasing only when the available water supply has been exhausted. Furr and Taylor (1934) have shown that there is a ready cross-transfer of water to all parts of the top when only a part of lemon-tree roots are in moist soil. Numerous observations made in the irrigated and unirrigated soil zones in commercial groves in the different irrigated citrus sections of southern California, after seasons of adequate winter rainfall, fail to show a material difference in the rates of soil-moisture loss from the same depths in both zones.

Soil types and changes in subsoil conditions, rather than irrigation prac-

tice, are probably the predominating factors in root distribution, except possibly when water applications are made so frequently as to prevent adequate aeration. Assuming the rate of soil-moisture extraction to be a measure of the distribution of absorbing roots, table 48 shows the apparent root activity of mature citrus trees in the different depths of some of the principal soil types in the citrus areas of southern California.

These measurements covered wide ranges in climate and in conditions of water delivery. Where comparisons were made in the same soil types, no evidence was observed of differences in apparent root activity that might be

TABLE 48

APPARENT ROOT ACTIVITY OF MATURE CITRUS TREES UNDER VARIOUS SOIL CONDITIONS, AS MEASURED BY THE RATE OF MOISTURE EXTRACTION

| Crop | Soil type | Depth of soil (feet) | Apparent root activity (per cent) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | First foot | Second foot | Third foot | Fourth foot | Fifth foot | Sixth foot |
| Lemons | Sandy loam overlying granite...... ... | 3.0 | 56 | 27 | 17 | .. | . | .. |
| Lemons | Sandy loam overlying granite.......... | 4.0 | 45 | 25 | 18 | 12 | .. | .. |
| Oranges | Sandy loam overlying granite subsoils | 4.0 | 46 | 26 | 17 | 12 | .. | .. |
| Oranges | Sandy loam overlying granite....... . | 5 0 | 35 | 26 | 20 | 14 | 5 | .. |
| Oranges | Sandy loam with coarse subsoil interspersed with strata of silt and sand.... | 6.0+ | 52 | 26 | 11 | 7 | 3 | 1 |
| Oranges | Sandy loam with coarse subsoil... .. | 6 0+ | 32 | 24 | 18 | 12 | 8 | 6 |
| Grapefruit | Sandy loam with coarse subsoil... .... | 6.0+ | 32 | 25 | 17 | 13 | 8 | 5 |
| Oranges | Loam with sandy loam subsoil .. . | 6.0+ | 34 | 30 | 16 | 11 | 6 | 3 |
| Oranges | Loam with medium subsoil..... .... | 6.0+ | 35 | 28 | 18 | 12 | 5 | 2 |
| Oranges | Loam with clay loam subsoil.. .... | 6.0+ | 46 | 27 | 16 | 6 | 4 | 3 |
| Lemons | Loam with clay subsoil...... .... . | 6.0+ | 55 | 21 | 13 | 6 | 5 | 0 |

attributed to climatic variations or differences in time or depth of irrigation. However, no observations were made in orchards obviously suffering from excessive soil moisture, except on sandy loams—soils with highly stratified layers of silt and sand in the subsoil which resulted in excessive soil-moisture conditions below a depth of three feet.

Lemon trees growing in soils underlain by heavy clay subsoils showed the shallowest rooting habits. Favorable soil-moisture conditions were found in the depths below three feet, and although the trees were allowed to wilt between irrigations this severe treatment seemed to have no effect in the extension of root growth into the heavy subsoils.

Smith, Kinnison, and Carns (1931) report the effect of variable frequency of irrigation trials on the root development of young Marsh grapefruit trees on sour rootstock in the light sandy soils of the Yuma Mesa. In these experiments, irrigation intervals of one, two, three, four, five, and six to nine weeks were followed during the summer irrigation season for three years. The average annual depths of water applied, including the effective rainfall, were approximately 84 inches for plot 1 irrigated at one-week intervals, and 44, 28, 24, 22, and 20 inches for plots 2, 3, 4, 5, and 6, which were irrigated at intervals

of two, three, four, five, and six to nine weeks, respectively. The average depth of each irrigation was 2.6 inches.

The removal of a number of trees from each plot, over the three-year period, gave an opportunity to study the effect of the different irrigation treatments on the root distribution.

The weekly irrigation schedule followed on plot 1 kept the surface soil moist and at a lower average temperature than in the other plots, and permitted an extensive root development the first year in the top six inches of soil. The root development in the top six inches in plot 2, irrigated every two weeks, was quite pronounced, but in the remaining plots it was appreciably less. During the first year there was a tendency toward an increase in root development at greater depths as the interval between irrigations was increased. This relative condition prevailed to a less degree in 1929, and the 1930 results indicated a tendency toward relatively shallow root development irrespective of soil-moisture conditions. The effect of increasing the interval between irrigations seemed to limit the total root structure rather than to force development into the lower soil depths where more favorable moisture conditions existed.

Part of the root system of a 25-year-old Washington Navel orange tree on sweet orange root was exposed by careful digging. This tree was planted in a contour row in a sandy loam soil exceeding 5 feet in depth. The longest root found was growing along the tree row in soil which was not cultivated and to which irrigation water was not directly applied. The root terminated 31.5 feet from the tree trunk and was 37 feet long. At no place was the root more than 1.5 feet below the ground surface, and at the free end was only 6 inches below the surface.

*Effect of irrigation on June drop and wind injury.*—June drop is the excessive shedding of young fruits, most of which occurs while the fruits are from one-half centimeter to two centimeters in diameter. The Washington Navel orange is particularly susceptible, especially when grown in the interior climatic zone.

Coit and Hodgson (1919) point out that unless there exists in the soil within reach of the absorbing roots a water supply sufficient to make up for that lost by the plant, a water deficit must eventually occur which will be followed by an abnormal shedding of the young fruits. These authors also discuss the possibility of modifying climatic and soil-temperature conditions by the planting of intercrops such as alfalfa, sweet clover, mustard, or vetch, which transpire large quantities of water, pointing out that this practice is justified only where the water supply is adequate to meet the needs of both trees and intercrop. It has not been demonstrated that the increase in relative humidity due to the cover crop is very great, or that this decrease in transpirational demand compensates for the increased competition for soil moisture.

Kinnison and Finch (1934) believe that under desert conditions transpirational demand might on occasions be greater than the absorbing and conducting system of the tree, and that the water deficit might adversely affect the quantity and quality of the fruit. In early summer this stress is reflected in an excessive shedding of young fruits, and in the latter part of the season by

loss of vigor and softening of the fruit suggesting that moisture is withdrawn from the fruit to be transpired by the adjacent foliage.

Shedding of young fruits has been observed to occur even when an adequate soil-moisture supply has been available; but the heaviest drop is usually associated with deficiencies in available moisture.

The effect of a lack of available moisture on June drop was observed in a plot of Washington Navel oranges at the Citrus Experiment Station, Riverside, in the summer of 1931, after the fruits had attained an average diameter of 35 millimeters (1.36 inches). During the six-weeks period June 29–August 10, plot 1, in which a supply of moisture available to the roots was present at all times, dropped an average of 107 fruits per tree. The trees in plot 2, from which water was withheld until the top foot of soil had remained at about the permanent wilting percentage for one week, lost in the same period an average of 358 fruits per tree, and plot 3, in which the top foot of soil had been at or below the permanent wilting percentage for two weeks and with the second foot at the permanent wilting percentage for one week, lost an average of 436 fruits per tree. The tree yields averaged 197, 94, and 84 pounds of fruit, respectively, from the three plots, showing the possible effect of excessive drying out of the soil even in the very last part of the so-called "June drop" period.

Reed and Bartholomew (1930), following a field study of severe wind injury, conclude that a large part of the damage from wind burn could be avoided by cultural and irrigation practices which promote water penetration and the full development of the rooting system of the trees. Trees that have a healthy, well-distributed root system and an available soil-moisture supply through the growing season will, other things being equal, suffer the least damage.

Observations made in an orange orchard near Somis, after a windstorm of high intensity and low relative humidity, showed severe burning of orange leaves but little or no injury to three lemon trees that were in different parts of the orchard. The orchard had just been irrigated. Soil sampling, taken to a depth of six feet, showed a very favorable moisture content below one foot throughout most of the soil. Cameron, of the California Agricultural Experiment Station, has made observations on the number of leaves and leaf surface of orange and lemon trees and has found that the leaf surface, on trees of comparable size, is much greater in the orange than in the lemon tree. This might explain why the lemon tree, growing under comparable conditions, does not transpire so much water as the orange tree, or show so severe injury during periods of desiccating winds.

*Effect of irrigation on the apparent rate of growth of citrus fruits.*—In 1919 Jensen reported some observations on the relation between increase in volume of lemon fruits and certain soil-moisture conditions. He found, in the Corona lemon district of California, that when irrigation water was applied at intervals of about fifteen days the lemons increased in size more rapidly than when water was applied at intervals of about thirty-six days. The seasonal amounts of water applied were about the same under both systems. He stated that the rate of fruit growth could be used as an approximate indicator of the moisture

requirements of the trees. Halma (1934) found that the growth of Washington Navel oranges seemed to follow the same general trend as the average soil moisture in the top two feet of soil. These observations were made with respect to three irrigation treatments. In treatment 1, a readily available moisture supply was maintained in the irrigated soil throughout the season. In treatment 2, soil moisture was reduced to about the permanent wilting percentage in the top foot of soil prior to each irrigation, and in treatment 3, water was withheld at each irrigation until the top foot of soil had remained at the permanent wilting percentage for about one week. In treatments 2 and 3, three periods in which soil moisture was not readily available occurred, the length of time that soil moisture was inadequate in treatment 3 being more severe than that usually found in commercial orchards.

Under treatment 1, with readily available moisture present throughout the season, the fruit made a steady growth except during the week of August 17–24, when the apparent growth rate was undoubtedly influenced by the extremely high temperatures prevailing during that period. However, the fruit showed a definite response to a rainfall of 1.43 inches on August 29, regaining in the period August 24–31 the loss in apparent growth rate incurred during the preceding week.

In treatments 2 and 3 the relation between soil moisture and apparent growth rate was marked. In both of these treatments there seemed to be a definite tendency for the apparent growth rate to slow up when the top foot of soil was still well above the permanent wilting percentage. Each irrigation in these treatments produced an immediate response in apparent growth rate, and at the end of the season the fruit from all the plots was practically of the same size. Plot 1, however, produced more than plots 2 and 3 combined, the difference in yield being caused primarily by the severe fruit drop on plots 2 and 3, as previously mentioned.

Data obtained by Halma and Beckett, presented in figure 165, show the response of Valencia oranges to widely different soil-moisture conditions. Plot 1, at the Citrus Experiment Station, received normal irrigation treatment, four irrigations being applied at four- to six-week intervals from June 14 to November 1, and with the exception of a short interval before the irrigation of September 20 all of the irrigated soil mass was above the permanent wilting percentage throughout the season. The response of the fruit to irrigation was very similar to that of the navel oranges, with a slowing up in the apparent growth rate before the permanent wilting percentage was reached in the top foot of soil and with a very definite increase in growth rate following each irrigation.

In plot 2, the breaking of an irrigation pipe line so much delayed the second irrigation that definite wilting of the trees occurred, resulting in foliage burn on the south side of the trees and a shrinking in the size of the fruit between August 12 and 19. There was a definite difference in fruit size in the two plots through the summer, owing possibly to the difference in climatic conditions of the two localities. However, it may be observed that even though the trees wilted badly in plot 2 prior to the irrigation of August 20, practically the same

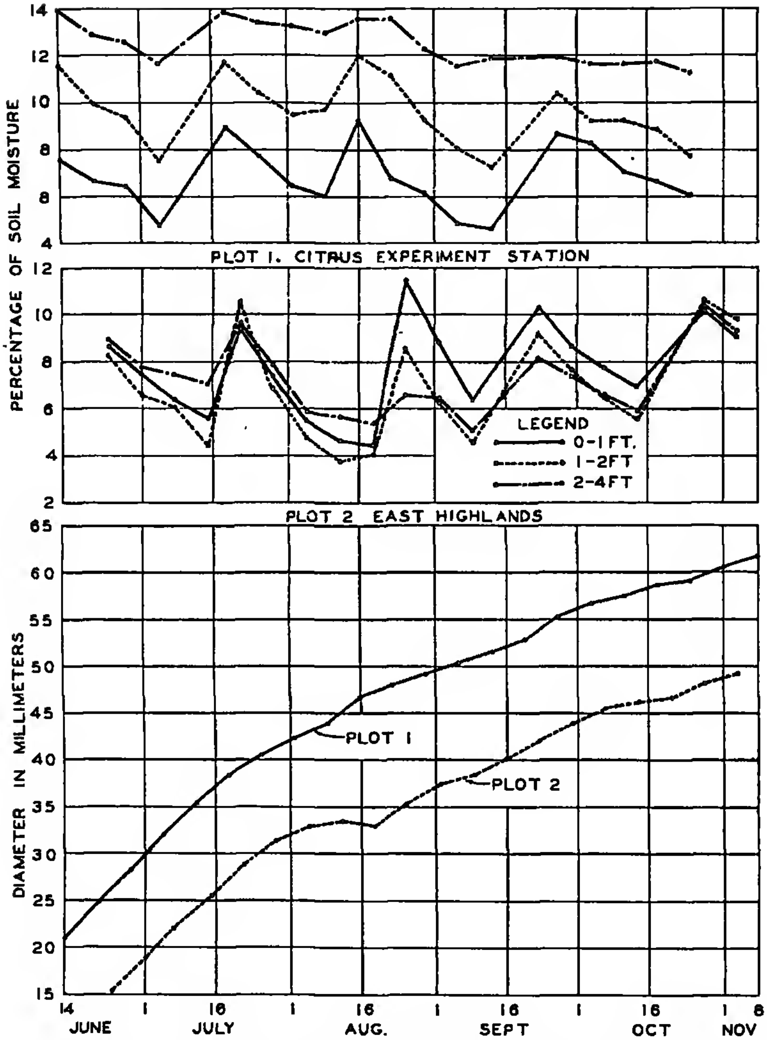


Fig. 165. Soil-moisture variations and rate of apparent growth of Valencia oranges under widely different soil-moisture conditions, at the Citrus Experiment Station and at East Highlands, California, season of 1932.

difference in fruit size in the two plots existed on October 31 as was measured on June 30. Furthermore, this drought in plot 2 resulted in neither fruit drop nor fruit splitting after the water was applied.

*Soil temperature in relation to transpiration.*—Bialoglowski (1937), working with rooted lemon cuttings growing in culture solutions under controlled root-temperature conditions, found that the rate of water loss through transpiration was slightly retarded at 35° C. (95° F.) and very markedly at root

temperature above 35° C. and below 15° C. (59° F.). This relationship is shown in figure 166. Girton (1927) measured the effect of temperature on the rate of root elongation of the sour orange and found that best growth occurred when the temperature was below 90° F., that at 93° F. growth had been reduced 50 per cent from the maximum rate, and that it ceased at 98° F.

Frequent irrigations of a grapefruit orchard on the Yuma Mesa, Arizona, maintained a lower temperature than was found where less frequent applications were made. The maximum temperature depressions produced by an irrigation were 4 to 10 degrees at 1 foot, 3 to 5 degrees at 2 feet, and 1 to 2 degrees

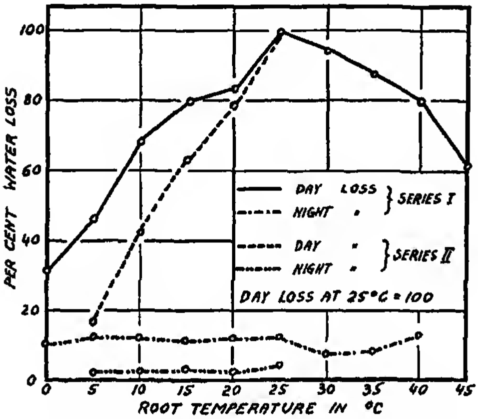


Fig. 166. Effect of root temperature on the rate of transpiration of rooted lemon cuttings. (After Bialoglowski, 1937.)

at 3 feet. Within ten days the effect of the irrigation on soil temperature was wiped out.

As Bialoglowski has shown, low temperature can affect water absorption by roots as adversely as high temperature. There is ample evidence that in cold winters soil temperatures fall so low as materially to affect water absorption by the roots. In the freeze of 1937 the soil temperature at the two-foot depth at the Citrus Experiment Station fell to 40° F., and at the same time the atmosphere was extremely dry, the minimum dewpoint reaching −8° F. The trees were severely wilted, leaf-water deficits exceeding 20 per cent being measured.

Since the specific heat of dry soil is approximately 0.2, less heat is required to raise the temperature of a dry soil a unit amount than is required for a moist or wet soil. The rate of heat transfer, however, is slower in a dry soil than in a moist one (Patten, 1909).

*Effect of irrigation on soil reaction.*—Various investigators have noted seasonal changes in soil reaction. Burgess and Pohlman (1928), working in citrus orchards where the soil was high in lime, showed that the trees were more chlorotic when a high soil moisture was maintained than when the moisture

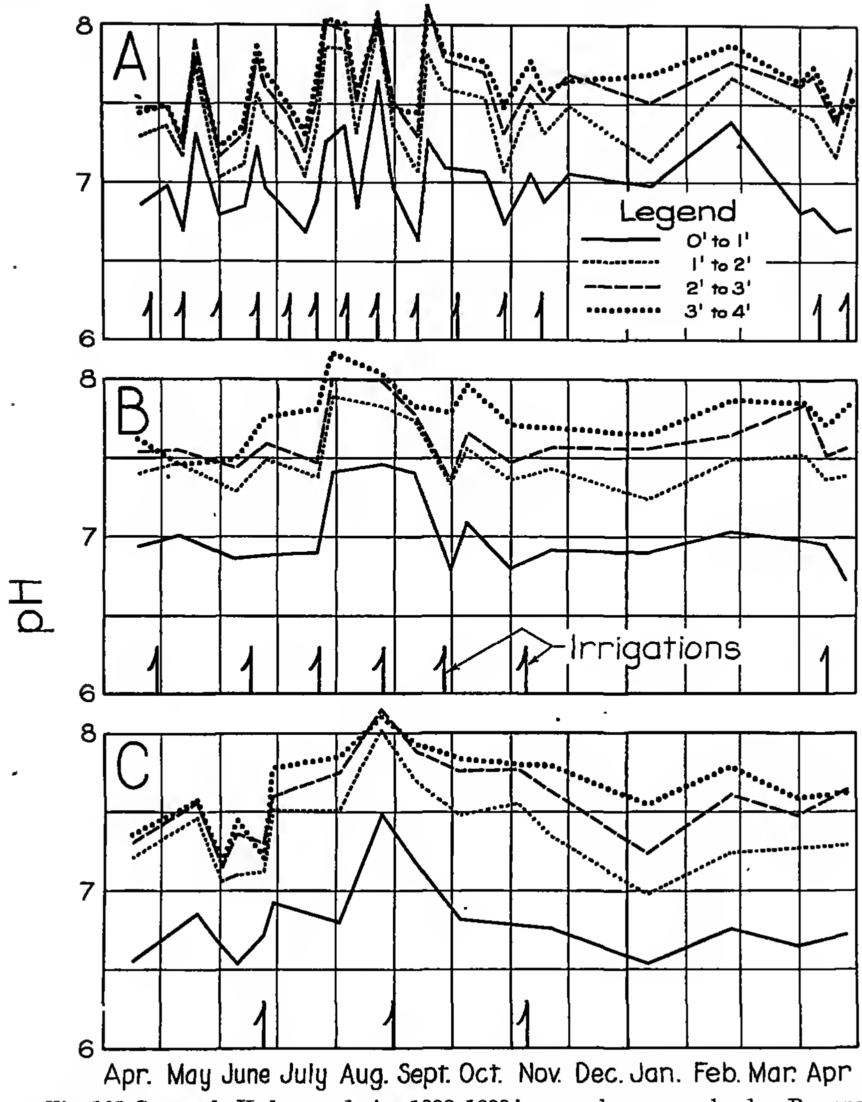


**Fig. 167.** Seasonal pH changes during 1938–1939 in a navel orange orchard on Ramona sandy loam soil under different irrigation treatments: A, plot received fourteen irrigations; B, plot received six irrigations; C, plot received three irrigations during 1938. (After Huberty and Haas, 1940.)

was allowed to fluctuate widely. The influence of frequency of irrigation on soil reaction is demonstrated in figure 167, which represents data collected at the Citrus Experiment Station, Riverside, on plots irrigated fourteen, six, and three times per season, respectively. The soil was less acid just after an irrigation than after it had dried.

## METHODS OF DETERMINING THE TIME TO IRRIGATE

The problem of obtaining a quick, reliable index for determining soil-moisture conditions is an old one. Some orchardists irrigate according to the calendar, others observe plant responses, a smaller number attempt to determine soil-moisture conditions, and still others try to correlate water use by the plants with evaporation rates from a free water surface.

Irrigation by the calendar is widely practiced, mainly because many citrus growers received their water from water companies that deliver it on a fixed schedule. Since the soil within an area served by a water company is seldom uniform in water-holding properties, an irrigation schedule proper for one grower might not be so for another. In attempts to evaluate irrigation needs more successfully, a number of indices have been developed, which will be briefly surveyed in the following paragraphs.

Many growers observe the trees for indications of color change, or wilt, which is associated with a low soil-moisture content in the soil occupied by the roots. A few use polaroid glasses to reduce the glare while making these observations. Some observe shallow-rooted plants growing in the orchard which might show water deficiency before the trees do. Although these methods are qualitative, a close observer of tree conditions can irrigate properly, provided he can get water on demand.

Other physiological responses that can be used as a guide to irrigation under certain conditions are fruit growth and leaf-water deficit. Jensen (1919) and Halma (1934) showed that the rate of fruit growth is associated with available soil moisture, a steady, uniform growth indicating adequate soil moisture. The lemon fruit appears to be more responsive to moisture changes than the orange or grapefruit. Fruit measurement (preferably circumference measurement) can be made at the same time of day and used as a guide to irrigation, especially in summer (Furr and Taylor, 1939). It is not always a reliable index in late fall in southern California, where the mild weather of early fall is often followed by high winds and extremely low relative humidity. The weakness in the method is that it may not indicate the reserve supply of soil moisture. Its chief advantage is the ease with which the measurements can be made. When this method is supplemented with soil-moisture sampling, a very reliable value is obtained. Esselen (1937), in South Africa, reports that fruit measurement is not a satisfactory indication of irrigation needs in that citrus-growing region.

Halma (1935) adapted the method of Stocker (1929) to study of leaf-water deficit in citrus. The basis of the method lies in the fact that when the rate of loss of water by transpiration is greater than the rate of absorption of water by the plant roots, the water content of the plant is reduced. The reduction in leaf water can be measured by the following procedure: Carefully select leaves of the same growth cycle from a designated location on the tree, or trees, and put them in a humid chamber; in the laboratory, remove dust from the leaves and weigh to the nearest hundredth of a gram; place the petioles of the leaves against the bottom of a beaker containing a depth of 1 centimeter of distilled

water; put leaves and container in a humid chamber for 24 hours; remove leaves and wipe off free water; reweigh. The leaf-water deficit is computed by dividing the gain in weight times 100 by the weight at saturation:

$$\frac{\text{Gain in weight} \times 100}{\text{Weight at saturation}}.$$

Compton (1937), in his studies at Riverside, found that Washington Navel orange leaves are severely wilted when the leaf-water deficit is as low as 7, and that the minimum leaf-water deficit at Riverside normally occurs about 4 A.M., the maximum between noon and 2 P.M. Oppenheimer and Mendel (1934), working in Palestine with Jaffa orange trees, found higher values.

Measurements of leaf-water deficit can be made by investigators and by orchardists who have laboratory facilities. While leaf responses are probably more sensitive than fruit responses to soil-moisture deficiencies, measurements of the fruit responses can be made more easily. This index has the same limitations as the fruit-measurement index.

Another method of testing the response of citrus trees to soil-moisture conditions is described by Oppenheimer and Mendel (1934). Kerosene is injected into the leaves, and the rate and extent of spread of the kerosene within the leaf is noted. Rapid and extensive movement of the oil indicates a turgid leaf; slow movement, leaves with high water deficits.

In general, it can be said that those methods which attempt to determine soil-moisture conditions by measurements of tree responses have much to recommend them. Most of the tests are easily and quickly made, and the values obtained represent the tree response to the soil-moisture conditions prevailing in the soil occupied by the roots. There are limitations to the tree-response tests, however, the principal drawback being that since the turgor of the plant is associated with atmospheric conditions, the tree responses may not indicate the true soil-moisture reserve.

Since the soil is used as a reservoir for the storage of moisture, it is natural that many attempts have been made to find a satisfactory means of determining the soil-moisture content. The most common method has been to obtain samples of the soil at various depths, usually by foot depths or by horizons, and to estimate the moisture content by examinations, or determine the amount of water quantitatively in the laboratory. As the soil is normally not uniform throughout an orchard, a sufficient number of samples should be taken to give a true over-all indication of the soil-moisture conditions.

Although soil sampling yields quantitative data on the moisture content of a soil, it is often laborious and expensive, and on gravelly soils it is unsatisfactory. For this reason quick-reading devices have been developed, including some that are electrical. Whitney, Gardner, and Briggs (1897) devised a method of evaluating the soil-moisture content by measuring differences in electrical resistance between two electrodes placed in the soil; but this method has not found favor, for three reasons: the electrodes corrode if they are left in the soil throughout the irrigation season, changes in resistance result from changes in the salt content of the soil, and the equipment is expensive.

Others have modified Whitney's method so that the differences in resistance normally resulting from corrosion and the presence of salines can be excluded. The method of multiple electrodes has been used by McCorkle (1931). Bouyoucos and Mick (1940) have in large part overcome this difficulty by encasing each pair of electrodes in a plaster-of-Paris block. The blocks are buried at the desired places in the soil, and the insulated lead wires of each block are brought aboveground, where a portable resistance bridge is used to make the measurement. The electrical resistance between the two electrodes buried in the block varies with the moisture content. For the blocks built according to the developer's specifications, soil at the field capacity has a resistance of about 500 ohms. As the moisture is depleted, there is little change in resistance until the moisture approaches the permanent wilting percentage, at which time the resistance changes rapidly. At the wilting percentage the resistance is in the neighborhood of 50,000 ohms. Plaster blocks that have been installed for four years in a citrus grove at the University of California Citrus Experiment Station are still in good working condition. The method provides good information on the soil moisture at fixed positions in the orchard.

Reeve and Furr (1941) have attempted to use the amount of water lost from a shallow evaporation pan as an index of soil-moisture extraction by citrus trees. A few growers have used the method in coöperation with investigators, but it has not been recommended for general use.

Measurements of soil moisture by electrothermal methods (Shaw and Baver, 1939), or by the dielectric method (Edlefsen, 1934; Fletcher, 1939), have not been tried in citrus orchards. It is doubtful that they will ever be widely used as a guide to irrigation practice.

Tensiometers are being used rather widely in experimental plots to study the tension at which the moisture is held. Because the soil-moisture range which they are capable of measuring is limited (Veihmeyer, Edlefsen, and Hendrickson, 1943), and because normally they are obstructions to cultivation, they have not been adopted by the citrus grower. Richards and Huberty (1941) report on their use in an orange grove at the Citrus Experiment Station, Riverside. A tensiometer equipped with a vacuum gauge has recently been developed and is now being tried out in commercial orchards.

## SUMMARY

In summary, it can be said that irrigation is relatively simple in orchards on deep, well-drained soil, in contrast to those on shallow, poorly drained soil. The deep, well-drained soil has a large capacity for water reception, and hence the danger of developing a condition of excessive moisture in it is small. Although soils may be irrigated so heavily that much of the soluble plant nutrients may be leached out, there is little danger that heavy irrigation will produce a saturated soil condition. The problem is to irrigate so as to maintain in the soil occupied by the tree roots the quantity of moisture that will prevent high water deficits in the trees. The amount of water required to moisten the soil depends upon the soil type. The frequency of irrigation will depend upon the climate and the extent of vegetative growth.

Very fine-textured soils, with poor internal drainage, are difficult to irrigate properly. A rather common practice on these soils is to use the alternate system of irrigation.

The irrigation practice on shallow primary soils (soil formed on bedrock), and on soils with heavy subsoils (claypan soils), should be to make lighter applications and at more frequent intervals than on the deep soils. Water should not be applied in amounts that would cause free water to be trapped above a dense claypan, for the moisture content of even the soil immediately above the water table will then be too high for good tree growth, and will be conducive to the growth of root-rot organisms.

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# Chapter XI

## DISEASES AND THEIR CONTROL

BY

HOWARD S. FAWCETT AND LEO J. KLOTZ

Important to successful citrus growing is the prevention and control of diseases, a long array of which are found on citrus if one takes into consideration all citrus localities in the world. In any particular country or locality, however, only a few of these diseases are likely to assume major importance. Many of them are found only occasionally, or are minor in importance, and others may be entirely absent from certain localities. The differences in climatic and other conditions between two countries, or even two localities in the same country, may be so great as to make diseases that are major in one place minor in the other. Many of the diseases described here are aggravated by neglect or mismanagement and usually are preventable with the exercise of due care. Some, however, are serious, and frequently require drastic measures and constant attention if they are to be prevented or cured.

The diseases are here arranged, for convenience of reference and identification, into groups corresponding, in general, to the parts of the citrus tree affected: (1) diseases of the fruit; (2) diseases of leaves and twigs; (3) diseases of trunks and roots.

Disease, considered broadly, is any condition of the plant or its parts which results in such a deviation from the normal structure or function as will injure or threaten the life of the tree or its economic usefulness. A variety of agencies and factors may produce disease: (1) animal organisms, such as nematodes, insects, and higher animals; (2) vegetable organisms, such as algae, fungi, and parasitic higher plants; (3) viruses; and (4) nonparasitic influences, such as malnutrition, physical factors of environment, and inherent weaknesses. Most of the diseases here discussed are those caused by fungi, bacteria, and viruses, or by detrimental influences in environment and nutrition. Insect injuries, some of which are often mistaken for diseases attributable to other causes, are discussed in chapters xii–xiv below. Diseases resulting from deficiencies and excesses of certain elements in the soil are discussed by Chapman and Kelley (see Vol. I, chap. vii), and by Batchelor (chap. vii above, on fertilization).

In the prevention and treatment of diseases three things must always be taken into account: (1) the effectiveness of the methods; (2) the cost of the treatments; and (3) possible injury to the plants. It is obvious that means of control must be employed that are less costly than the losses caused by the disease. Prevention of diseases caused by parasitic organisms is brought about by various means, depending on the nature of the disease: (1) keeping down sources of infection; (2) avoiding conditions which contribute to infection; (3) covering the susceptible parts with fungicides or disinfectants to prevent entrance of the organism; (4) employing resistant species or

varieties; and (5) excluding the parasitic organism from the orchard or locality, or even the entire country, where it has not yet become established.

In the following discussion of diseases, emphasis will be placed mainly upon description of the diseases and of means for their control. Limitations of space require that this be brief and concise.

A more detailed discussion of the history of citrus diseases, their geographic distribution, the nature of their causes, and the conditions contributing to their occurrence, with numerous references to the literature, will be found in *Citrus Diseases and Their Control* (Fawcett, 1936). Most of the references to the literature prior to 1936 will be found in that book, and only a limited number of them will be repeated here. Additional illustrations in color will be found in *Color Handbook of Citrus Diseases* (Klotz and Fawcett, 1941*b*). Market diseases are also illustrated by Rose *et al.* (1943) and Bratley *et al.* (1944). Some further history of citrus-disease research is reported by Fawcett (1941*b*).

## DISEASES OF THE FRUIT

The fruit diseases considered in relation to the type of the lesion and the tissues of the fruit affected (including blemishes and physical effects, as well as effects resulting from the attack of organisms) may be grouped into three main divisions: (1) definite decay or rots; (2) internal derangement apart from definite decay; (3) external spots, markings, eruptions within the rind or upon its surface.

### Fruit Rots

The fruit rots are of three different types: (1) the rots that are soft and easily punctured by a slight pressure of the finger; (2) rots occurring in such a manner that the rind is pliable and leathery and is not so easily punctured by light pressure of the finger; (3) rots that are firm and dry and that often affect all or part of the interior of the fruit.

#### COMMON GREEN MOLD

This form of soft decay, which is due to *Penicillium digitatum* Sacc., is world-wide in distribution in orchards, packing houses, and markets. It begins almost invariably as a result of some injury to the rind.

*Symptoms.*—A water-soaked, soft area appears which in the market is often called "blister rot." This enlarges rapidly, and a white mycelium appears on the surface, followed later by the development of olive-green spores which form a dust cloud when disturbed (fig. 168). The chief characteristics of the disease while the soft areas are enlarging are the following: (1) A wide white margin of mycelium surrounds a central green area of spores. (2) This white area of mycelium is usually pasty and wrinkled. (3) The paper wrapper used in packing adheres to the fruit. In these three respects the green mold differs from the blue contact mold, characteristics of which are that the white mycelium forms a narrower band and is powdery, not pasty, in appearance, and that the paper wrapper does not adhere so readily to the moldy fruit. The common green mold alone rarely shows a bluish green color; but it does so if, as frequently occurs, it is mixed with the blue contact mold.

Besides the mechanical injuries that open the way for the common green mold, secondary effects may result from the presence of oil or juice liberated from the fruit. This citrus oil has an injurious effect upon the surface cells, causing them to break down and thus allows the entrance of molds. If juice from injured fruit comes in contact with the surface of other fruits, an ideal medium is supplied for the germination and entrance of molds.

*Control.*—Common green mold is controlled mainly by careful handling of the fruit during all operations of growing and picking, packing-house treatment, and marketing, so as to avoid injuries and abrasions. Careful handling is generally supplemented by treating the fruit with some solution. The details of control for this mold and the following one are discussed below.

### BLUE CONTACT MOLD

This second form of soft decay caused by ***Penicillium italicum*** Wehmer[1] is somewhat similar to the previous one (fig. 168). It is also probably world-wide in distribution. To an appreciable degree it is also caused by injuries. As compared with common green mold, however, it can spread more readily from one fruit to the next by contact, apparently through the uninjured skin and often, in fruits of low vitality, through the stem end. For this reason it is called a contact rot (fig. 176, *A*, p. 508). In early stages, before the white mycelium and blue spores appear, it is frequently called "pinhole" decay or "blister rot."

*Symptoms.*—A water-soaked, soft area appears, surrounding some injury or abrasion. Ordinarily, this area is more easily punctured by pressure of the finger than that caused by common green mold. Usually, the initial spots also enlarge more slowly than those of common green mold. As the spot enlarges, an area of blue spores is formed, which is surrounded by a narrow band of white mycelium and, beyond this, a halo of water-soaked, faded tissue between the fringe of white mycelium and the sound tissue. After the rot is well started, blue spore masses may develop inside at the core or in the inner spongy part of the rind.

Frequently, both the blue and the green molds are associated (see fig. 168), and it is usual to find the common green mold appearing after the blue mold has first begun to break down the fruit. The mycelia of both the molds extend to the very edge of the softened tissue, and the effect, as seen with the microscope, even upon the protoplasm of the cells, can be detected only for a distance of 0.2 to 0.3 millimeters beyond the invading hyphae.

*Control of common green and blue contact molds.*—The control methods are practically the same for both the common green and the blue contact mold. Emphasis should be placed on avoidance of injuries which may originate in numerous ways, since decay from these molds starts from the germination and growth of spores in injured areas, and with or without injuries when in contact with other decaying fruit.

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[1] Some decays of citrus fruits, usually of minor importance, have been associated with *Penicillium verrucosum* in South Africa, *P. expansum*, *P. stoloniferum*, and *P. roseum* in California, *P. fructigenum* and *P. olivaceum* in Japan, *P. insigne* and *P. candidum* in Italy, and *P. crustaceum* in Puerto Rico (Fawcett, 1936, p. 400).

To prevent decay from blue and green molds: (1) pick fruit when it is thoroughly dry; (2) handle fruit carefully, so as to avoid injuries during all operations from tree to market, in picking, hauling, washing, grading, sizing, packing, shipping, and marketing.

Some of the means of preventing injuries are: (1) providing gloves for pickers and handlers of fruit; (2) using suitable clippers; (3) taking care to avoid ladder bruises; (4) avoiding injuries in emptying picking sacks; (5) having dry field boxes with bottoms entirely boarded and free from rot residues, nails, splinters, gravel, or sand and litter; (6) filling boxes not too full; (7) loading and hauling with care not to jostle fruit; (8) supervising the picking crews; (9) using only those types of unloading conveyances which transport fruit gently; (10) using suitable, well-painted machinery to prevent injuries; (11) avoiding careless emptying of fruit at washer, and picking out fruit with wormholes, decay, and fresh injuries; (12) avoiding accumulations of rubbish and decaying fruit in packing house; (13) using care in putting on box covers after packing, to prevent injury to fruit by undue pressures; (14) using care in loading in cars or ships. Also, at regular intervals the washing equipment should be thoroughly cleaned and the brushes sterilized. In fact, general sanitation throughout the packing house at all times is advantageous in reducing decay.

A supplementary aid for partial prevention is washing fruit in one of the following solutions, with or without (3) below: (1) borax (for oranges and grapefruit, when handled fresh, but not for grapefruit, or for lemons placed in storage), 5 to 8 per cent, or a mixture of 4 per cent borax and 2 per cent boric acid in hot water; (2) anhydrous sodium carbonate, commonly known as soda ash (for lemons and grapefruit if they are to be stored), 1¾ per cent by weight in hot water; (3) nitrogen trichloride gas, 5 milligrams per cubic foot for 3 hours once or twice weekly on oranges in precooler (Klotz, 1936). Oranges, such as Tulare County navels, when brought into the packing houses, are exposed to 6 to 14 milligrams[1] of the gas for 3 hours (6 hours, if fruit is fully matured). This treatment may be repeated once or twice, depending upon how long the oranges are held, and a final treatment may be given to the packed and loaded fruit in the car. Lemons and grapefruit in storage are treated one or more times weekly, depending upon the prevalence of decay, with 1 to 2 milligrams per cubic foot of nitrogen trichloride for 4 hours, and in the car also, if necessary, with the same dosage and exposure.[2]

Since the amount of decay that subsequently develops is more or less directly proportional to the concentration of spores in the air and on surfaces of equipment, the spore load should be kept low. Dumping and cleaning

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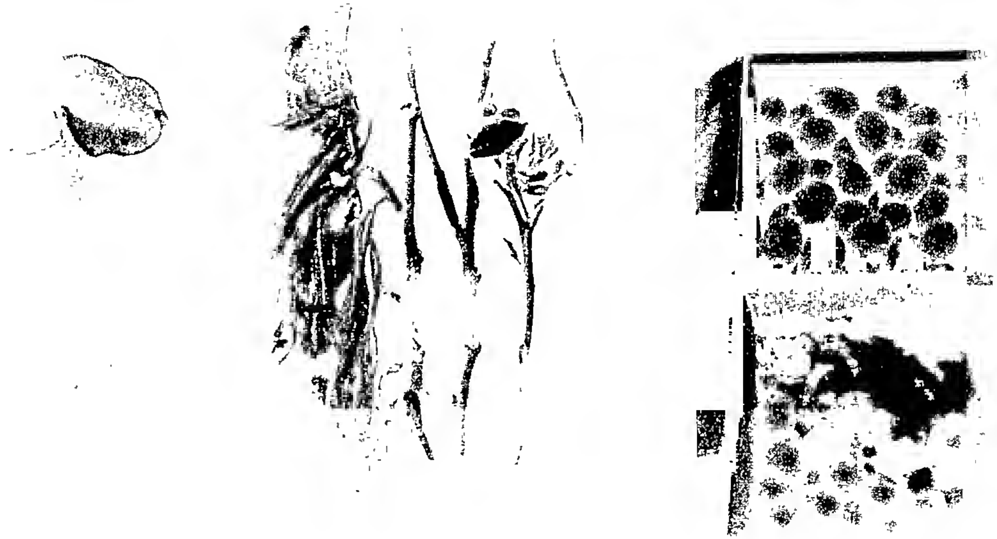
[1] Or a commercial reading of 0.05 to 0.10 p.p.m. Cl in water in Hellige color comparator for orange storage and 0.01 to 0.02 parts per million for lemon storage.

[2] Fruit wrappers impregnated with a decay-inhibiting substance should be mentioned as a possible supplementary aid. Several chemicals have shown experimentally good promise of decay control under rigid trials. These are (*a*) the terpineols such as alpha terpineol and allied complexes and (*b*) chlorine-bearing compounds that liberate chlorine gas slowly. It is important that the odor of the wrapper should not be offensive to the packers or consumers and that the fruit flavor should not be contaminated. (From unpublished notes by Dr. R. A. Baum.)

Fig. 168. *Top,* decay by green mold (*Penicillium digitatum*); *center and bottom,* decay by mixtures of blue mold (*P. italicum*) and green mold.



*A* *B* *C* *D*

Fig. 169. *A*, toadstool of the cottony-rot fungus, *Sclerotinia sclerotiorum*, growing from sclerotium; *B*, root rot; *C*, twig blight; and *D*, fruit decay caused by the fungus.

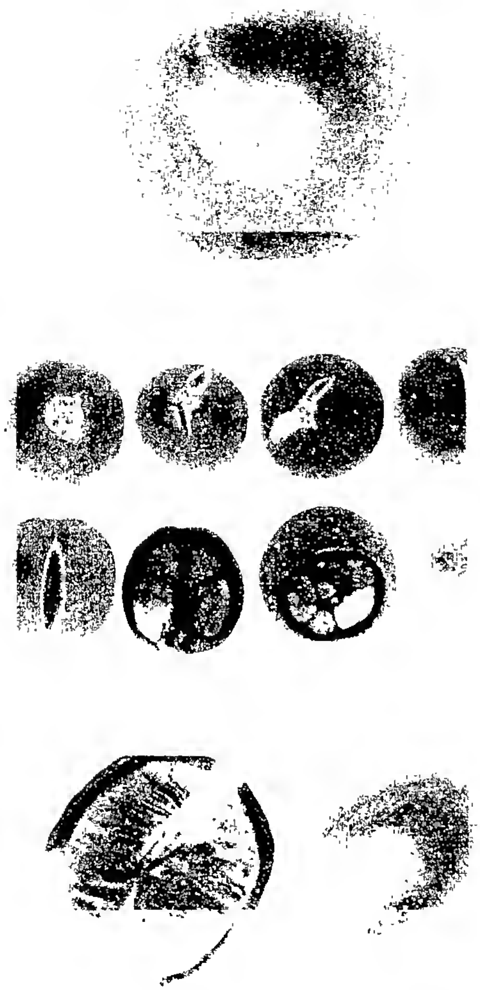


Fig. 170. *Top*, Pleospora rot caused by *Pleospora herbarum*; *middle*, splits and black rot; *bottom*, Alternaria rot caused by *Alternaria citri*.

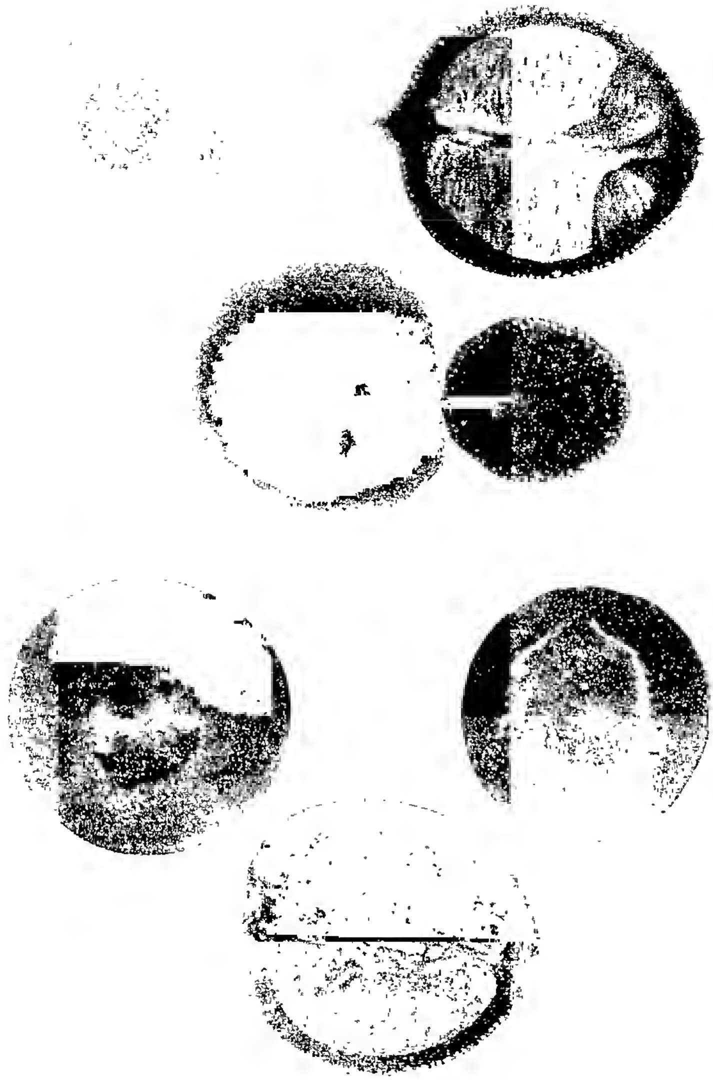


Fig. 171. *Upper three*, internal decline (endoxerosis) of lemon; *lower three*, stylar-end rot of Tahiti (Persian) lime.

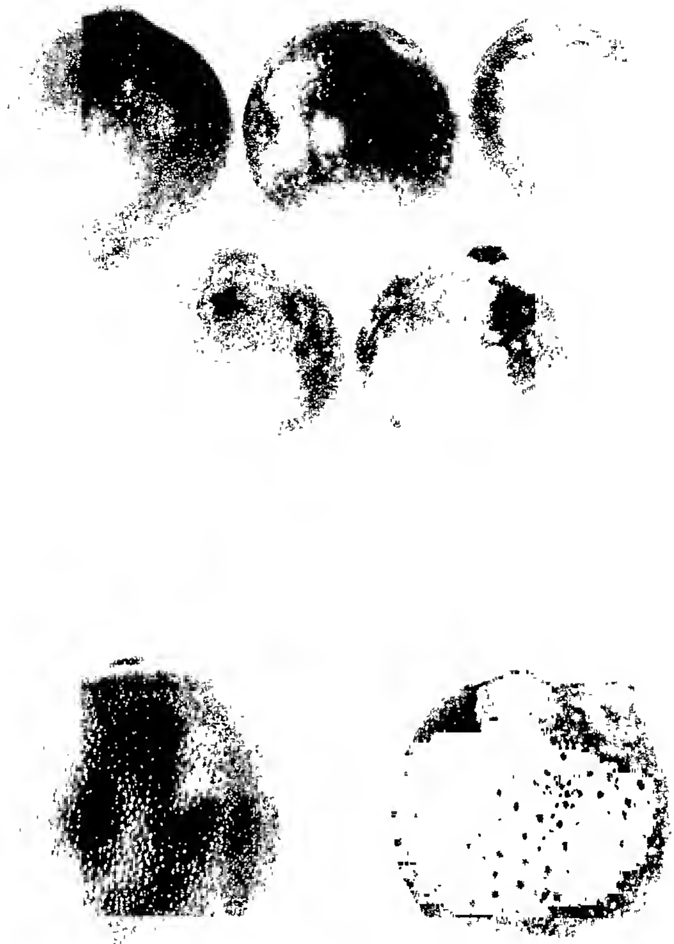
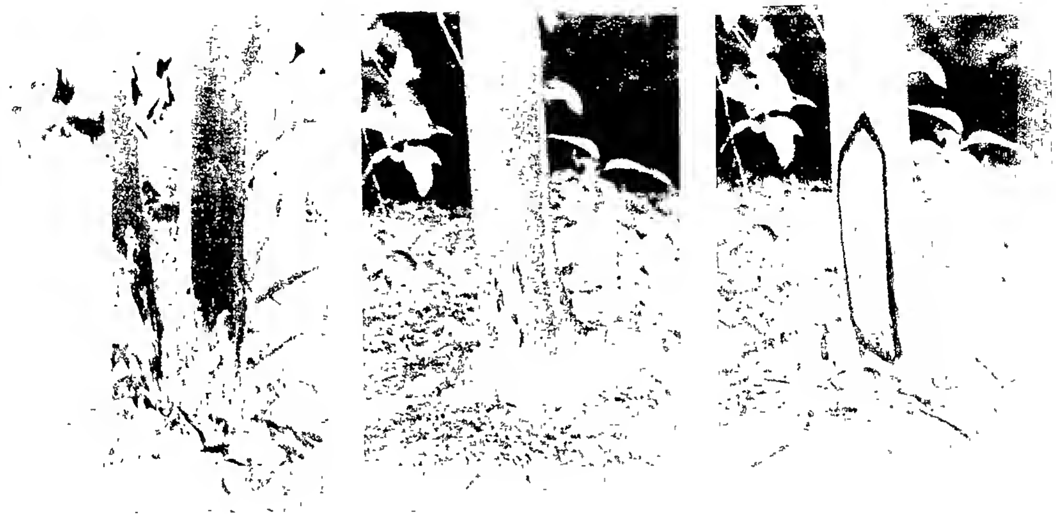
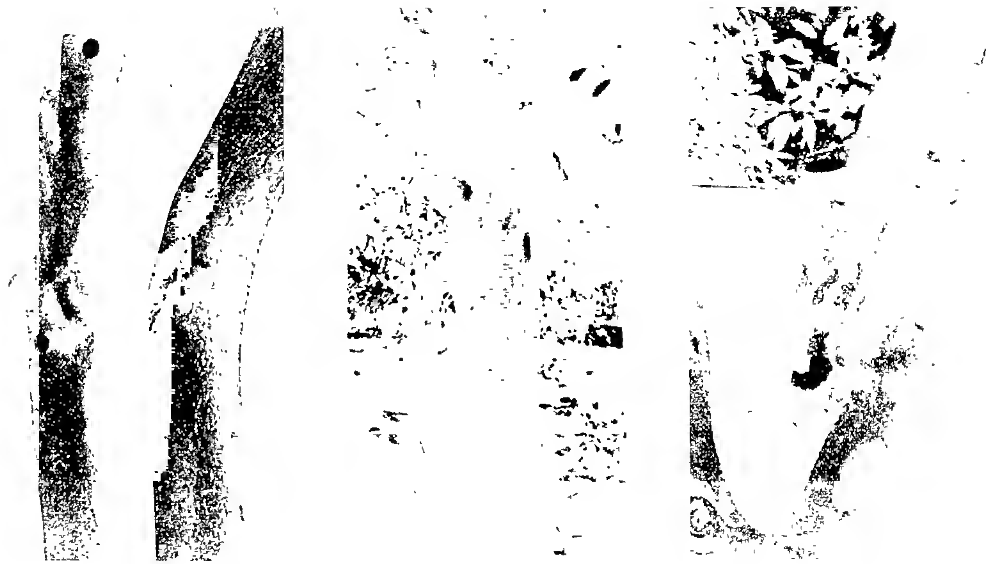


Fig. 172. *Above*, red blotch or adustiosis; *below*, albedo browning.



*A* *B* *C*

Fig. 173. *A*, Foot-rot type of gummosis on grapefruit; *B* and *C*, lemon trunk with gummosis, (*B*) before and (*C*) after treatment.



A B C

Fig. 174. Types of psorosis caused by *Citrivir psorosis*: *A*, concave gum psorosis, caused by *C. psorosis* var. *concavum*; *B*, blind-pocket psorosis; and *C*, eruptive blind-pocket psorosis caused by *C. psorosis* var. *alveolatum*.

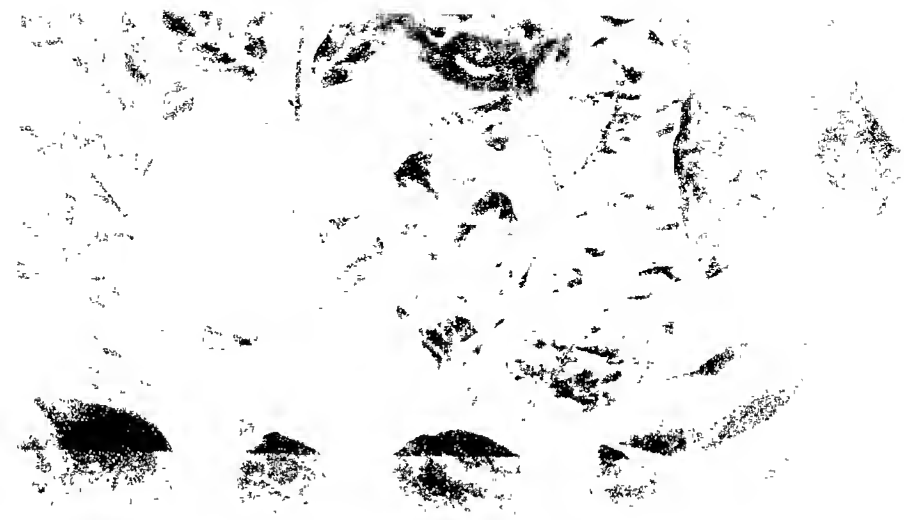


Fig. 175. Crinkly-leaf and infectious variegation caused by a variety of psorosis virus.

should be done in a separate room, if that is possible, to avoid contaminating the processing and packing rooms. Some packing houses are also reducing decay by disinfecting the houses with chlorine gas (3 oz. per 1,000 cu. ft.) just before the start of the regular packing season,[1] or by atomizing thoroughly all surfaces with pine-oil emulsion.[2] Rots should be disposed of carefully and promptly, and the whole packing house kept thoroughly clean. For deodorizing, a chloride-of-lime suspension may be used in scrubbing floors and other surfaces.

### OÖSPORA ROT, OR SOUR ROT

Sour rot is a soft, slimy, contact decay caused by the fungus *Oöspora citri-aurantii* Ferraris. It most often occurs on mature lemon fruit in storage. The tissues soften quickly after infection and become more watery and more easily punctured than tissues infected with the green or blue mold. The decaying areas at first become creamy yellow, then dark buff, and finally, as the water-soaked hyphae show on the surface of the rind, a light buff. The fruit finally collapses, becomes slimy, and changes into a watery mass from which liquid drips. Fruit flies are especially attracted to it, and thus the mass is soon filled with maggots and pupal cases.

The sour rot is frequently associated with other forms of decay, such as brown rot and blue and green molds. Mixture of the sour-rot organism, Oöspora, with nearly any of the ordinary mold fungi, especially with the *Penicillium* species, greatly speeds the rate of decay (Savastano and Fawcett, 1929). This explains why decay appears to increase so rapidly when this fungus is present in stored lemons.

It is prevented by keeping the fruit free from injuries, by washing the fruit in hot water or hot solutions, by shortening the period of storage, and by taking other precautions like those used against blue and green molds. When sour rot is prevalent, frequent inspection of stored fruit is advisable.

### BROWN ROT

Brown rot of citrus fruits is caused by any of the following fungi: *Phytophthora citrophthora* (Sm. and Sm.) Leonian, *P. parasitica* Dastur, *P. syringae* Kelb, *P. boehmeriae* Sawada (Frezzi, 1941), *P. palmivora* Butler, and *P. cactorum* Schroet (Klotz, unpublished). The motile spores (zoöspores)

[1] Chlorine gas released into the air of the storage or sweat room and rapidly mixed to give small, safe concentrations, and hypochlorites dissolved in cold water in concentrations yielding 0.04 to 0.06 parts per million of available chlorine, have been tried on pure cultures of these fungi and found very effective in killing them (Klotz, 1936, and Hwang and Klotz, 1938). It may be possible to dilute and then release, distribute, and maintain for the necessary time an effective and safe concentration of chlorine gas in a storage room containing fruit, and experiments to that end should be encouraged; but the difficulties have not yet been surmounted. Concentrations were either too great and damaged the fruit, or, when they were low enough to be safe, they could not be maintained and were ineffective. Chlorine combines so readily with moist surfaces that it weakens quickly from its effective concentrations and disappears. Some lemon-packing houses are using hypochlorite supplemented by a solution of sodium-o-phenolphenate.

[2] A: Water containing ½ per cent soda ash and ½ per cent soap powder. B: A stock solution having by volume 20 parts white pine oil, 18 parts cleaning solvent, and 2 parts red oleic acid. Mix in proportion of 99½ gallons of A to ½ gallon of B.

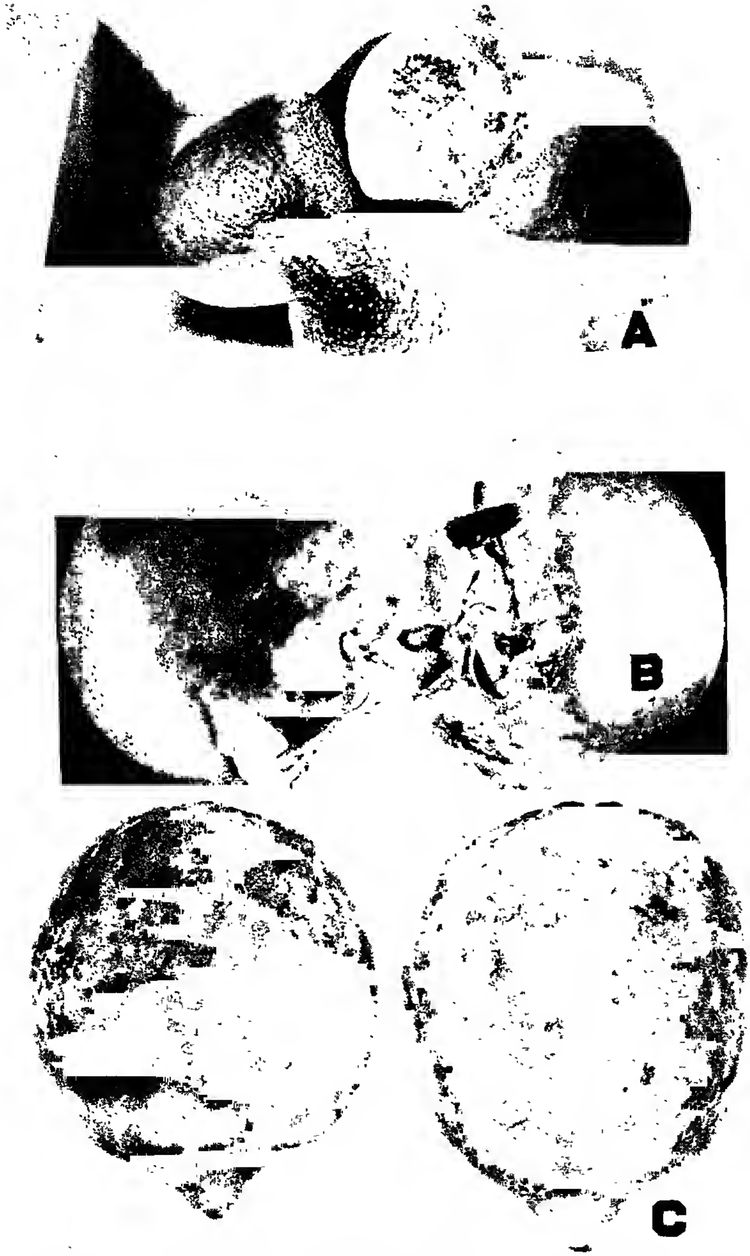



Fig. 176. *A*, blue mold (*P. italicum*) producing contact decay; *B*, decay by *Botrytis cinerea*, starting from fallen petals; *C*, Botrytis decay of lemons.

of certain strains of *P. cinnamomi* Rands (Fawcett and Bitancourt, 1940*b*) and *P. drechsleri* Tucker may, also, infect uninjured lemons and oranges. The decay has been reported in most of the citrus-growing sections of the world; it occurs principally in the orchard, but may become troublesome at times as a contact rot in the storage rooms of packing houses. Some of the same fungi (*P. citrophthora, P. parasitica, P. cinnamomi,* and *P. palmivora*) also cause brown-rot gummosis, which is discussed further on.

*Infection and symptoms.*—The swimming spores which form on the surface of moist soil are splashed by rains against the low-hanging fruit—usually within three feet of the ground surface. If strong winds accompany the rains, the zoöspores may be carried throughout the entire tree and infect a large proportion of the fruits and flowers, and even the shoots may develop a gummy blight (Speroni, 1942). Within three to ten days, small dark discolorations appear on the surface of the infected fruits, and later develop to various shades of drab or brown (fig. 177). The tissue at first remains firm, then becomes leathery, and finally soft as blue and green molds invade. A characteristic odor distinguishes it from all other rots. In the open air, mycelium is rarely visible on the fruit surface, but in a moist atmosphere a white delicate mycelium appears and spreads the decay rapidly by contact.

*Control.*—Where brown rot seriously affects an orchard, and where abundant rains and long periods of wet weather frequently occur, a 6-6-100 bordeaux mixture (6 pounds of copper[1] sulfate, $CuSO_4 \cdot 5H_2O$, and 6 pounds of hydrated lime, $Ca(OH)_2$, to 100 gallons of water) may be applied to the ground beneath the tree and to the trunk and foliage to a height of three or four feet (Klotz and Fawcett, 1939*a, b*; 1941*a*; 1942*a, b*; 1944*b*; Klotz and Parker, 1945; Klotz, 1941*a, b, c*; 1943*a, b*; 1944*a, b*). For ordinary conditions the maximum concentration of copper suggested is that of the 3-3-100 bordeaux mixture. This may be further diluted to 1-1-100, to decrease liability to injury where cyanide fumigation is practiced (Klotz and Lindgren, 1944). Even with this low concentration, a period of four or more weeks and at least a moderate rainfall should separate spray application and fumigation, if injury to leaves and fruit is to be avoided. The addition of zinc sulfate to the spray has been observed, on a few occasions, to decrease the injury from fumigation. A formula employing 5 pounds of zinc sulfate (22.7 per cent metallic zinc), 1 pound of copper sulfate, and 4 pounds of hydrated lime to 100 gallons of water is used. This spray will also correct mottle-leaf resulting from zinc deficiency if it is applied to the entire foliage.

Laboratory experiments have indicated that organic chemical tetrachloro-*p*-benzoquinone (1 pound in 100 gallons) approaches the effectiveness of 1-1-100 bordeaux mixture (Klotz and Middleton, 1943). Moreover, it did not aggravate fumigation injury. In field experiments, however, its protective

[1] In the seasons 1944–45 and 1945–46, serious damage resulted in some orchards from the use of copper-containing sprays (Klotz and Middleton, 1945). Pitting of leaves and fruit appeared, and some gumming and defoliation of twigs. No satisfactory explanation of this sudden toxicity of copper sprays to citrus has as yet been found. One theory is that the acid gases from the new war industries near the citrus-growing areas are making the relatively insoluble deposit more soluble and releasing toxic copper ions.

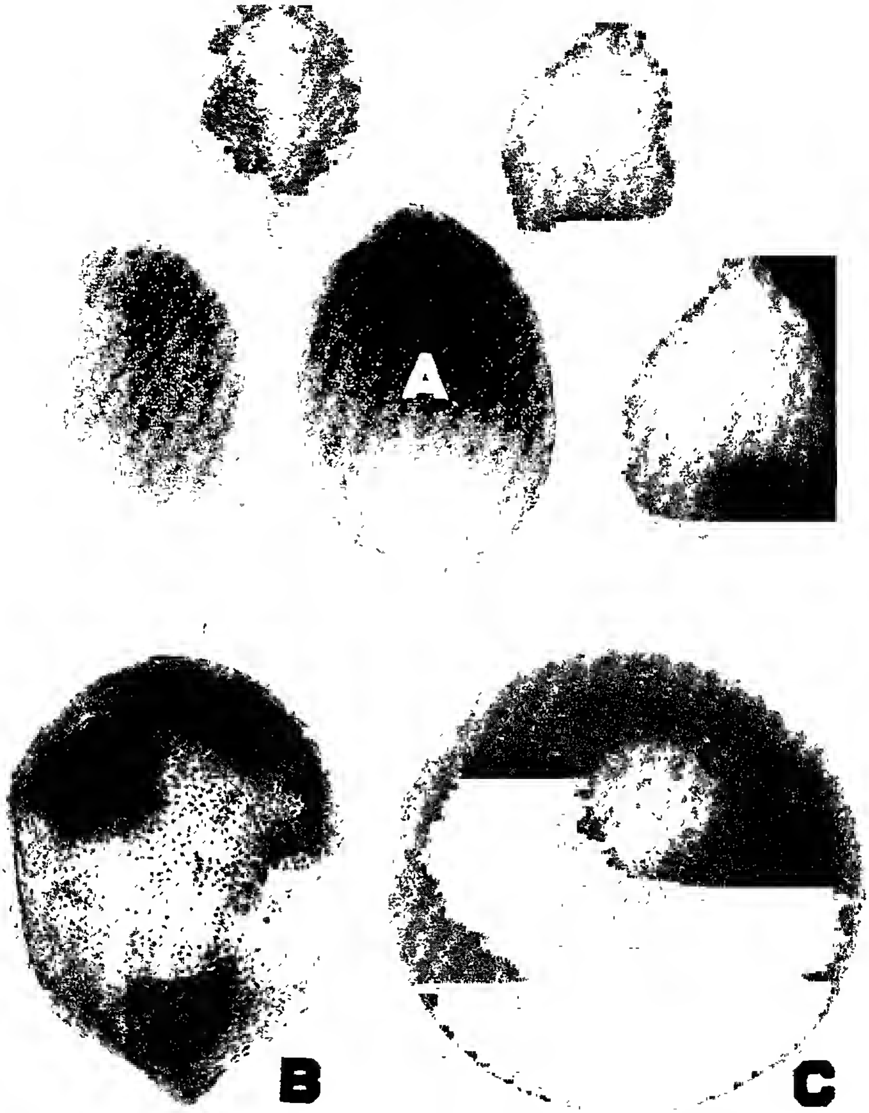



Fig. 177. *A* and *B*, brown rot caused by *Phytophthora citrophthora;* and *C*, by *P. syringae.*

effect soon began to diminish, and eventually ceased entirely. An effective sticker and spreader should be added when the sprays described above are used. In recent experiments, the most effective adhesives and spreaders, as judged by amount of copper retained after weathering and by degree of protection afforded against brown rot, were those containing mineral oils. Next in effectiveness were casein (the parent protein, not its salts) and whale oil-rosin soap. Two other new organic fungicides, zinc dimethyl-dithio-carbamate (2 pounds in 100 gallons) and disodium-ethylene-bis-dithio-carbamate (1½ pounds with 1 pound of zinc sulfate and ½ pound of hydrated lime), have afforded satisfactory protection of lemons in laboratory experiments and in some field experiments (Klotz and Zentmyer, 1946). While their protective effect does not last as long as that of bordeaux mixture, their use is suggested where severe copper damage has occurred or where HCN fumigation must soon follow the spray.

In the packing house, brown rot is prevented from spreading by immersing all fruit for at least 2 to 4 minutes in: (1) hot water at 115°–120° F., or (2) 1¾ per cent solution of anhydrous sodium carbonate (soda ash) either cool or hot, or (3) a solution of copper sulfate—1 to 2 pounds to 1,000 gallons of water. The continuous type of submergers should be used (Klotz, 1941*a, b, c*; 1943*a*; 1944*c, d*).

When either of the first two methods just described is employed, the turgid fruit of the winter crop must first be conditioned by drying to a slightly wilted state before it is immersed, in order to prevent the liberation of toxic rind oil. Lemons picked in or after a period of dry weather should be held from 36 to 48 hours before being subjected to the hot-water treatment; if picked soon after a rain, they should first dry in the packing house at least 4 days before the hot immersion. If crowded conditions make preconditioning infeasible, lemons should not be washed in solutions with temperatures exceeding 100° F. Oranges, though less sensitive than lemons to rind-oil liberation and injury, should be kept at least a day between picking and processing. For lemons at 65° F., an immersion of 2 minutes at 120° F. will prevent decay by killing the fungus in the upper layers of cells of the rind even though, for as long a time as 30 hours previously, the fungus may have penetrated the fruit surface. Cold toxic solutions, although they prevent infection of sound fruit in the washer, kill only those parts of the fungus with which they come in contact (Klotz, 1943*a*).

## COTTONY ROT

The cottony-rot fungus, *Sclerotinia sclerotiorum* (Lib.) Mass., causes twig blight (p. 548) and root rot (p. 567), as well as a decay of all varieties of fruits (fig. 169, p. 500). It is especially injurious on lemons in storage, where the infected fruits develop a rot that is at first leathery and pliable, and later, as the white aerial stage (fig. 176, *C*) of the fungus appears, soft and dripping. Within the white cottony mass are formed black, compact, seed-like bodies (sclerotia), which under field conditions develop small toadstools (fig. 169, *A* and *B*). From the upper surface of the toadstools, spores escape

explosively and may infect fruit if they lodge in a fresh wound on the fruit surface. Decay later develops in the fruit, whether in storage or in transit.

*Control.*—Although no orchard spray can be applied economically for the prevention of fruit and twig decay, other precautions should be practiced in the field. Picking boxes should not be allowed to become contaminated by being left in contact with wet soil and cover crops for long periods. Cover crops may be temporarily discontinued in those orchards the fruit from which has shown large quantities of storage decay from this fungus. Twig infection, which occurs more abundantly after frost injury, may be ignored, or the dead twigs may be pruned out at the time of removal of deadwood. In the packing house, washing the fruit in hot water or hot 1¾ per cent soda ash solution at 117°–120° F. for 2 minutes or more, or at 114°–120° F. for 3 minutes or more, as for brown rot, will kill spores and vegetative parts of the fungus that can be reached by the chemical and the heat. Spores in the deep wounds may escape the washer treatment and later develop the serious contact rot of the storage fruit. The decay will spread from one box to the ones below it by dripping from the rotting mass. Inspection of storage, and elimination of decays and contacts, should be thorough and frequent.

## BOTRYTIS ROT

The Botrytis rot or "gray mold" caused by *Botrytis cinerea* Pers. is somewhat similar to the preceding. Besides occurring on fruit in storage or in transportation, it may also occur in the orchard. It spreads by contact, but less rapidly than the cottony rot. Its initial stage somewhat resembles that of cottony rot; in later stages its main characteristic is a gray instead of a white mold on the surface. When it appears on lemon fruits, the surface becomes cinnamon drab or cinnamon brown, later turning to shades of buff brown or dark brown (fig. 176, *C*; p. 508). When it occurs on oranges, the color may be medium to dark yellowish brown.

The fungus lives on a variety of decaying matter in the orchard, such as leaves, petals (fig. 176, *B*), twigs, fruit, bits of wood, or other vegetable matter in the tree or soil. The spores may be carried by wind, water, insects, or other carriers. It develops principally in cool, moist weather, and slight frost injury appears to render the tissue more susceptible to the fungus.

The means of control for Botrytis rot are mainly the same as those for cottony rot previously described.

Investigation has shown that Botrytis and Sclerotinia have caused increased abscission of young lemon fruits in Ventura County groves (Tyler, 1946; Klotz, 1946*c*; Klotz, Calavan, and Zentmyer, 1946). The floral parts, principally the petals and stamens, are attacked, and abscission of the enclosed ovary, and of young fruits with which the fungus mass comes in contact, is induced by chemicals that are formed, and by a toxic state that is set up, by the fungi. The sepals and young fruits are apparently not invaded by the fungi until after abscission. Copper sprays applied when wet foggy weather occurs during the blooming will protect the young fruit and decrease loss from dropping.

### TRICHODERMA ROT

Trichoderma rot, produced by *Trichoderma lignorum* (Tode) Harz, may at times cause much loss in lemon storage. It starts at injuries, at a devitalized stem end, or by direct contact of a sound fruit with a decaying one, and since the fungus can readily invade the wood of the fruit boxes the wooden partitions cannot confine the decay. It frequently accompanies other common decays. Although it is firm, it is somewhat pliable, is brown to cocoa brown in color, and has a coconut-like odor.

The fungus starts as a whitish growth, which turns greenish yellow and various shades of yellowish and bluish green as the spores are formed. While the organism attacks and destroys citrus fruits, it plays a beneficial role in the seedbed, where, if the soil reaction is in the range of pH 4.0 to 5.5, it protects citrus seedlings from *Rhizoctonia solani* and other damping-off fungi (Weindling and Fawcett, 1936).

Since the decay usually occurs under the same conditions as those which bring about blue and green molds in storage, the means of prevention indicated for the latter are usually sufficient for the control of Trichoderma rot.

### ALTERNARIA ROT, BLACK ROT, CENTER ROT

Several types of decay and spotting may be caused by *Alternaria citri* Ellis and Pierce (Fawcett, Klotz, and Nixon, 1936; Bliss and Fawcett, 1944) or related species of fungi. This fungus is also found in Alternaria spot of fruit and leaves (p. 525). The decay in oranges is usually different from that in lemons. In oranges it is generally known as black rot; in lemons, as Alternaria rot or center rot. In oranges, especially in navel oranges, the black rot is most often noticed just before the crop colors on the tree.

*Symptoms.*—The infected orange fruits become deeply colored sooner than the sound fruits and turn a deep orange color. The fruits often appear sound on the exterior, but show, when cut, a black, firm, decayed place within or near the stylar end. The structure of the navel orange, with its secondary fruit at the stylar end, makes it especially susceptible to black rot. The dry interior decay is mummy brown to black and proceeds slowly in sound tissue (fig. 170). It usually occurs near the ends only, and to one side of the navel end. In South Africa, Wager (1939*a*) has found that oranges with large navel ends tend to develop the navel-end rot, and that the large navel ends result (1) from harsh weather conditions when the fruit is 0.2 to 0.3 inch in size, and (2) probably from water abnormalities when the fruit exceeds 1.5 inches in size.

In lemons the decay takes, in general, two forms: (1) In mature fruit of low vitality there is a soft breakdown of the central axis or core, brought about by entrance of the fungus from the button or stem end. Such fruits may appear outwardly sound, but under slight pressure they crush easily. The soft, disintegrated condition of the interior differs strikingly from the dry, firm, black rot of oranges. The color of the interior takes on shades of brown to nearly black. (2) On fruits of higher vitality there may be a slower

gradual browning of the exterior, also. The consistency varies from firm, pliable, leathery to soft, pliable, and the color from chestnut brown to olivaceous black.

*Control.*—Black rot in oranges is rarely thought to require preventive measures. Occasionally, however, there are seasons when a large proportion of navel oranges are affected. It then becomes necessary to cull at the packing house, so far as possible, all oranges with Alternaria rot in them, since they break down rapidly on the way to market (Bartholomew, 1926). The decay, though slow, often opens the way for green and blue molds.

The production of strong, resistant fruit of high vitality is the chief means of controlling Alternaria rot in lemons. It requires (1) proper soil fertilization, irrigation, protection against wind and against too low temperatures, and the like; (2) picking fruit before it has been too long on the trees, especially the tree-ripe fruit; (3) maintenance of good storage conditions and the avoidance of prolonged storage of fruit of low vitality, especially that which is slightly damaged internally by frost or which shows internal decline or membranous stain; and (4) elimination from shipment, so far as possible, of fruits of low vitality, especially in warm summer and fall weather.

### ANTHRACNOSE ROT

(See also Anthracnose of twigs and leaves, p. 540, and Anthracnose spots, p. 524)

Anthracnose rot, a soft, pliable rot most often found in mature, overripe fruit, is caused by the Anthracnose fungus, *Colletotrichum gloeosporioides* Penz. In lemons it is often similar to the stem-end type of Alternaria rot. Frequently, both Alternaria and Colletotrichum enter the same fruit. Most of the strains of *C. gloeosporioides,* and some species in the related genus *Gleosporium,* are unable to cause serious rotting in fresh, vigorous fruits of high vitality. The decay starts either as a small, brown area around the button or stem end or around rather severe injuries to the rind of mature fruit. The same fungus produces hard, dry spots on the surface of fruits and sometimes tear stain as well. As the decay progresses, the areas become dark brown to almost black. Fruits appear to be most subject to this rot when slightly injured by frost or other conditions that lower their vitality, even though no visible effect can be seen preceding the decay.

### PHOMOPSIS STEM-END ROT

Phomopsis stem-end rot, which is caused by *Diaporthe citri*[1] (Faw.) Wolf, starts as a firm, pliable decay at the button end of the fruit. The same fungus causes melanose (p. 533) and is usually an important secondary factor in shell bark (p. 558). The rot varies with the degree of maturity of the fruit and with the moisture present. Starting with a slight softening and discoloration around the stem button on oranges or lemons, it changes to drab and brown in color and becomes more pliable under pressure of the finger. Inside

[1] The fungus is usually seen in its imperfect or Phomopsis stage.

the fruit, the light-brown decay advances rapidly through the core and the inner white portion (albedo) of the peel. In California, the rot occurs only as a minor decay on fruits of low vitality in storage; but in Florida in some citrus-growing areas it frequently causes serious losses of fruit in transit. The rot is also occasionally found in fruits in the orchard.

*Control.*—Measures practiced in Florida for the protection of oranges and grapefruit may be summarized in directions as follows: Prune the trees to remove the deadwood as a source of infection. Between April 15 and May 5, spray with a 6-6-100 bordeaux mixture containing 1 per cent heavy mineral oil emulsion, or make two postbloom applications of 3-3-100 bordeaux with 1 per cent oil emulsion, separated by a month's interval as required for melanose control. Pick the fruit before it is overmature. Grapefruit may be debuttoned by pulling instead of clipping as it is removed from the tree. Clipper-picked grapefruit and oranges may be debuttoned by the use of ethylene gas within 4 days after picking. Wash the fruit in 7 to 8 per cent borax solution at 110° F. Keep the packed fruit at 45° to 50° F. Ship and market as rapidly as possible.

Good control has been obtained experimentally by dipping fruit in 4 to 10 per cent solutions of thiourea, but because it may be a danger to the health of human beings the chemical cannot be used commercially.

## DIPLODIA AND DOTHIORELLA ROTS

This form of decay, caused by *Diplodia natalensis* Pole-Evans[1] and the Dothiorella stage of *Botryosphaeria ribis* Gros. and Dug., or related organisms, usually begins at the stem end, but may also start at the stylar end or at injuries to the rind. Like Phomopsis stem-end rot, it is a leathery, pliable decay, and in its early stages cannot readily be distinguished from that form of decay. It most often occurs in fruit that is in storage or in transit from orchard to market.

*Symptoms.*—As in decay caused by Phomopsis, there is at first an almost imperceptible discoloration around the button, soon followed by a leathery, pliable condition and a drab to brown color; the decay is usually darker both externally and internally than that produced by Phomopsis. On oranges it may show wide bands on the surface, corresponding to the division of the segments within; it is usually accompanied by exudation of amber-colored, sticky juice; and as the entire fruit is rotted, the color becomes dark olive green to black. One of the California strains of Diplodia often produces a dark lavender color inside, and a California strain of Dothiorella produces under the same conditions a brown color inside. There is so much variation, however, in both of these fungi that the final stages of decay produced by them cannot be easily distinguished. Both of them usually have a stronger, more penetrating odor than Phomopsis stem-end rot.

[1] The perfect stage of this fungus is *Physalospora rhodina* (B. and C.) Cooke (Stevens, 1926; also Voorhees, 1942). Another *Diplodia*, *D. sarmentorum* (Fries) (Wollenweber, 1941), is also capable of producing a similar decay. This was identified by Neil Stevens from some of the specimens originally thought to be *D. natalensis* Evans from California, Sicily, and South America, in a list and accompanying letter to H. S. Fawcett, May 4, 1940.

*Diplodia natalensis* also produces a decay of limes called charcoal rot. It begins on mature limes as a copper-colored brownish spot. As the process of decay approaches completion, the fruit dries and is filled with black, hard, charcoal-like masses of fungus mycelium.

*Control.*—The control of Diplodia and Dothiorella rots is mainly the same as for the Phomopsis stem-end rot (p. 514). The fungi causing them, however, appear to be more resistant to copper than the Phomopsis fungi, and hence the spraying recommended in Florida for Phomopsis stem-end rot may not be so good a preventive measure against them. The trees should be kept in a vigorous condition free from scale insects, the deadwood removed so far as good orchard practice requires, the fruit kept, if possible, at low temperatures after picking, and the period between picking and consumption shortened as much as possible.

### INSPISSOSIS, OR DRY ROT

This rot, produced by either of two yeastlike fungi, *Nematospora coryli* Peg. or *N. gossypii* Ashby and Nowell, consists in a thickening and drying of internal tissues of the fruit without manifestation of external symptoms. In advanced stages of the disease, the juice vesicles, besides being dry, are greatly thickened. On citrus fruits the disease has been reported in the Philippines, South China, and the West Indies, and more recently in the Imperial Valley, California, and in Florida. The yeastlike fungus appears to be carried into the interior of the fruits through punctures made by certain insects.

*Symptoms.*—In the Philippines, the early stages of this rot on the segment walls of the fruit show a white, mealy texture, and sometimes the flesh becomes dry and brittle. Vesicles separate easily from one another, and become dry and free from juice; and their walls thicken. The fruits also have an unpleasant taste. In advanced stages of the rot, they become dry and almost tasteless. On grapefruit and oranges in the Imperial Valley, California, and in Florida the juice vesicles just inside the rind collapse and often later become slightly brownish in color and tend to dry out rapidly.

*Control.*—It is likely that the only efficient method of control would be to prevent the attack of the puncturing insects which appear to carry this disease mechanically. An investigation in the Imperial Valley, California, disclosed that it was carried from the pomegranate to citrus by the puncture bug, *Leptoglossus zonatus* (Dallas), and that it did not occur on citrus except near pomegranate trees.

### MISCELLANEOUS FORMS OF DECAY

The following fruit rots causing decay are of minor importance and will not be described here. Descriptions of them will be found in *Citrus Diseases and Their Control* (Fawcett, 1936) at the pages indicated: Pink mold, page 399; Aspergillus rot, 403; Rhizopus rot, 405; Rolfs Sclerotium rot, 405; Pleospora rot, 435; Fusarium rot, 438; Candelospora rot, 465; Rhizoctonia rot, 464; Mucor rot, 465; Phoma rot, 465; Hendersonula rot, 464; Poria rot, 465; and Thelaviopsis rot, 464.

None of these rots are known to cause much damage under ordinary conditions, and if their control should become necessary the methods described above for similar rots would probably be found effective.

### Internal Breakdown and General Effects

Besides the definite forms of decay there are internal breakdowns and deteriorations which can scarcely be designated as decay or rot. Most of those to be considered here have not been found to result from the presence of organisms, but have been attributed to environmental effects. Although they are not true rots, they often open the way for some of the rots previously mentioned.

#### ENDOXEROSIS, OR INTERNAL DECLINE

A gummy breakdown beginning usually in the peel of the stylar end of lemons is known as internal decline or endoxerosis. Growers and packing-house workers have given it other names, including blossom-end decline or decay, dry tip, yellow tip, pink tip, and tip deterioration. It may be confused with Alternaria rot, which frequently accompanies or follows it. In California it usually makes its first appearance in the orchard in May or June, and reaches a maximum in the dry summer and autumn (Bartholomew, 1937).

*Symptoms.*—Externally, the affected green lemon may show a loss of luster or a yellow color at the stylar end. As the fruit matures, the rind surface surrounding the nipple is depressed and the nipple may bend toward the deeper part of the depression. Internally, in the albedo of the rind, pinkish to rust-brown-colored masses in the vicinity of gum-filled vascular bundles are frequently found near the nipple and in the core. In advanced stages of the disease these are found in any part of both albedo and core. If the veins of the affected parts, especially of green fruit, are cut through, gum may appear as drops. Collapse and drying of the juice sacs follow and progress until all or nearly all of the pulp of the stylar half is affected (see fig. 171). Usually, the fruit then drops from the tree.

*Control.*—Observation and experiments indicate that the principal causes of internal decline are related to water conditions within the tree and fruit, which in turn are influenced by the temperature of the soil and its supply of moisture, mineral nutrients, and organic matter, by the abundance and condition of the feeder roots and general condition of the tree, and by the temperature and humidity of the air. Internal decline is therefore less severe in plantings near the coast, in orchards protected by adequate windbreaks and with sufficient irrigation, fertilization, and other good orchard practices that are favorable to tree health.

If all colored fruit, regardless of size, is removed early in the spring, and if the lemons are picked promptly as they approach picking size—a smaller ring being used in years of severe decline,—much of the trouble can be avoided. In the packing house, experienced workmen, judging by external symptoms, can eliminate most of the affected fruit at the washer. Severely affected lemons float with the stylar end upward, owing to air space in that portion. (See also Vol. I, p. 692.)

STYLAR-END ROT

Stylar-end rot is a breakdown most commonly found in Tahiti or Persian limes, but occasionally occurring in other limes and in lemons. The depressed areas, which are firm and fairly dry, start as water-soaked, whitish to drab, sunken patches at the base of the tip, and progress until from one-fourth to one-half the fruit is affected. Internally, there develops a condition somewhat resembling endoxerosis, as the tissue dries and collapses (see fig. 171, right). No means of prevention is known. Part of the loss may be avoided by picking fruit before it becomes too mature. Stylar-end rot may occur in climates with high humidity if the tree roots absorb insufficient water. Maintenance of optimum soil-moisture content should help to prevent the rot, and the measures suggested under "Endoxerosis" should help to decrease its occurrence. A breakdown of lemon fruit indistinguishable from stylar-end rot was induced by storing the fruit at high temperatures (105° to 110° F.) and high humidity (96 per cent) for 36 hours (Klotz, unpublished).

MEMBRANOUS STAIN, OR MEMBRANOSIS

Membranous stain, or membranosis, is an internal breakdown of lemons which develops in stored fruits, particularly in old fruit and other fruit of low vitality. The membrane partitions or carpellary walls between the pulp segments become discolored a light to sooty brown or black in irregular but definite areas (fig. 178, *B*). The central core sometimes shows the staining. Although membranous stain shows no external symptoms, it usually accompanies the later stages of red blotch and, occasionally, peteca (see p. 521). All three of these breakdowns are favored by inadequate ventilation and by storage temperatures that are held much below 55° to 58° F. for long periods. With some alteration in packing-house practices or equipment it is usually possible to improve storage conditions and decrease these troubles.

Orchard factors that seem to favor the later development of the trouble are frost, periods of low but not necessarily freezing temperatures, drying winds, and large fluctuations in the moisture content of the soil. These can be modified to some degree by adequate frost and wind protection and care in soil-moisture control.

EXCESSIVE FRUIT DROP, OR CARPOPTOSIS
(INCLUDING JUNE DROP)

Excessive fruit drop may occur in two phases: excessive shedding in the immature stage, and excessive dropping as the fruit approaches maturity. The former is commonly known in California as "June drop" (Coit and Hodgson, 1919) and in South Africa as "November drop" (Wager, 1939*b*), and the latter as "fruit drop." Sometimes it is difficult to distinguish between normal and abnormal dropping. Excessive shedding of fruits, in both phases, may be due in part to adverse climatic conditions, unfavorable conditions of water supply and nutrition, or injuries caused by insects and fungi. Two or more of these factors may often be operating together, or one following another, so that it is difficult to separate their effects; most important, apparently, are unfavorable

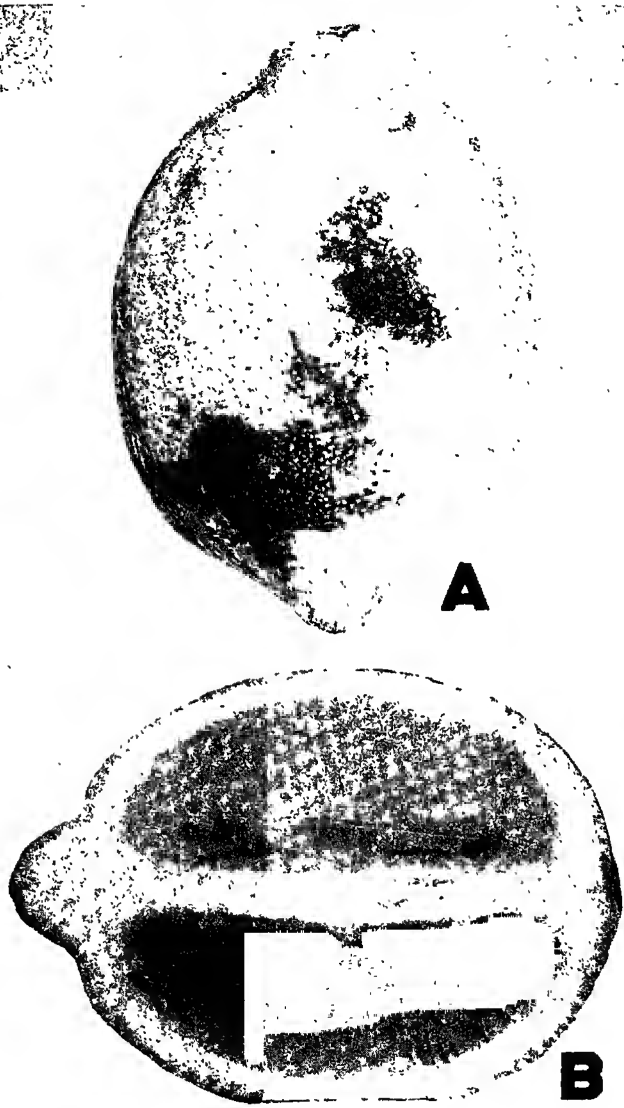



Fig. 178. *A*, rind-oil spot or oleocellosis; *B*, membranous stain or membranosis.

conditions of climate and nutrition. There appears to be a close relationship between excessive shedding and lack of available nitrogen. In South Africa, Wager (1939*b*) judged that excessive drop is a result of harsh weather conditions such as high temperatures, low humidities, and strong winds.

Preliminary experiments in which sprays of growth-regulating materials were applied for the checking of the drop of both immature and mature fruit have been encouraging (Stewart, Klotz, and Hield, 1947).

### GRANULATION, OR SCLEROCYSTOSIS

Granulation, technically called "sclerocystosis" and referred to inappropriately as "crystallization," is found most often on fruit picked late in the season. It is often referred to as "dry end." In California it is mostly found in Valencia oranges.

It usually starts near the stem end, and extends first in the region close to the core. Separation of cells near the center of the juice sacs allows air to enter, giving the sacs a clear-white appearance. The sacs become hard and firm by a thickening and stiffening of their walls. Finally, a dry, woody, solid condition results. Rapidly growing and larger fruits have a greater tendency to show granulation than more slowly growing, smaller fruits. Some rootstocks tend to induce it more than others, especially the Rough lemon (see chap. ii, p. 119, above). Early picking may avoid some of the losses from granulation. Fluoroscopic examination has been found helpful in eliminating affected oranges. For details of this disease see MacRill (1940), Bartholomew, Sinclair, and Turrell (1941), and Volume I, page 690, of the present work.

### FRUIT GUMMING

Gum formation within the fruit or on its surface frequently occurs and takes on various forms. Gum at the navel cavity of green orange fruits may be due to invasions of organisms at an early stage. Defective development of a segment of the fruit may also give rise to gum formation. Gum may form at the surface of small green fruits as a consequence of fumigation injury or of insect injuries such as those caused by *Tortrix* or by grasshoppers. Gumming may occur as a result of deficiencies or excess of various mineral elements.

Gum forms in the albedo of the rind and in the core from boron deficiency, and in the angles of the segments toward the center in exanthema resulting from copper deficiency (see "Exanthema," p. 535 below, and "Copper," chap. vii, pp. 360–361). Gum deposits in the albedo and core are usually found in lemons affected with internal decline. During periods of fairly high temperature, some gum may result from the invasion of organisms such as Alternaria fungus and canker bacterium.

### EXTERNAL SPOTS, MARKINGS, AND ERUPTIONS

The external spots, markings, or other effects on the surface of citrus fruits may be roughly divided into three general types: (1) those which are usually sunk below the surface of the surrounding normal tissue of the rind; (2) those which are raised above the surface of the surrounding tissue, either as pustules or as scablike prominences not easily rubbed off; and (3) superficial pustules and markings that are readily removed by rubbing. Some of these may be considered as definite diseases; others merely impair the appearance of the fruits until they are removed.

The cause of many of these effects is often difficult to determine, because different agencies may produce the same physiological effect, often resulting in the same type of spot or reaction of the host tissue. It is also true that the same agencies under different growth or climatic conditions may produce different physiological effects.

### RED BLOTCH AND ALBEDO BROWNING

These two diseases of storage lemons seem to be aggravated by inadequate ventilation and forced curing at high temperatures and humidities with ethylene gas. Red blotch, or adustiosis (fig. 172), begins as a superficial reddish brown discoloration, particularly on lemons picked when immature and when the weather is cold. The color darkens until it assumes various shades of brown to almost black. Lemons from certain groves are more prone to develop the trouble than fruit grown elsewhere, and one grove is known the fruit from which invariably develops red blotch after a few weeks in storage, thus suggesting an inherent rind weakness. Besides the inherent susceptibility of certain lemons, some products of respiration such as ethyl acetate and other alkyl esters are thought to play a part in inducing the rind breakdown. Unlike red blotch, which starts on the surface of the rind, albedo browning begins in the inner rind, or albedo (fig. 172). Both diseases open the way for infection with blue and green molds and other types of storage decay.

### PETECA

Peteca is a deep pitting or sinking of the surface of the rind, usually some time after the fruit is picked. It may sometimes appear on some fruits before picking, especially during or following cold weather, and if a heavy oil spray has been used. The tissues underneath the pits in the albedo or white part of the rind are dry and shrunken, at first light and then dark in color.

### STORAGE SPOT, OR POX

Shallow, sunken spots varying in size and shape may occur on fruits stored under unfavorable conditions of temperature and humidity. On grapefruit, pox may begin as small indentations of the rind, which increase in size and depth. The spots gradually turn brown, especially on exposure to warmer temperatures. They are formed by the breaking down of layers of tissue containing the oil vesicles. Pox is usually most troublesome at 38° F. and below. For storage of lemons and grapefruit the temperature should be 57° to 60° F. and relative humidity 86 to 88 per cent. Air should be circulated at the rate of 1 cubic foot per storage box per minute, or up to 600 cubic feet per carload (406 packed boxes). Fresh air at the rate of 90 cubic feet per car per minute should be added continuously if the fruit is of good or normal vitality and condition; if it is in poor condition as a result of frost damage, sunburn, decline, and decay, it may be desirable to double the intake of fresh air, because injured fruit respires faster. Early California navel and Valencia oranges, if not treated with ethylene, may be held in a precooler at 35° to 37° F. and 90 to 95 per cent humidity for a period not exceeding 4 weeks. If they are treated with

ethylene, no storage is recommended. The air in the precooler room of the packing house should be circulated at a rate of not less than 3,000 cubic feet per minute per car for 72 hours; 20 to 25 cubic feet per minute of fresh air per car should be added continuously. After the fruit is cooled, circulation may be reduced to 1,000 cubic feet per car per minute.

### VALENCIA RIND SPOT

In California this spotting and pitting develops in the late summer and autumn on mature or overmature Valencia fruits of the coastal sections. Losses due to spotting and the dropping which follows it have been reported as amounting even to 25 per cent of the crop in some groves. Valencia rind spot is found almost invariably in the stem half of the orange, the shoulder portion and the area around the stem being most frequently affected. Spots seem to start from slight injuries, or even from the collapse of single oil glands, without apparent mechanical injury. The areas are at first only slightly sunken and barely discolored; later, the surface collapse is severe and the spots darken to various shades of brown. The breakdown appears to be aggravated by cyanide fumigation, washing, and the use of ethylene. Anthracnose and Alternaria fungi may become established in the affected areas, causing further enlargement and darkening.

Observation and experiment indicate that hot weather with rain, fogs, or high humidity during the later part of the Valencia season may hasten the development of this rind spot. Few suggestions can be made for avoiding it; where feasible, the fruit may be picked earlier so as to avoid overmaturity and the necessity for treatment with ethylene (Sloop, 1942).

### RIND BREAKDOWN

Rind breakdown, especially of mature fruit, occurs principally on navel oranges which have matured during mild weather. The injury follows wet weather with low temperatures, whether the temperature has been low enough to freeze the inside of the fruit or not. There may be liberation of oil internally and externally, together with collapse of cells just under the cuticle, even without visible breakdown of oil glands. This results in brownish yellow to dark brown stained spots. Imitations of rind breakdown have been produced by injections and external applications of orange-rind oil at low temperature and high humidity. The use of ethylene gas, and immersion of the oranges in hot water while they are still turgid, appear to aggravate the effect after the fruits are picked.

### BLACK PIT

Black pit caused by *Phytomonas syringae* (Van Hall) Bergey is most noticeable on lemon fruits, but may be found also on oranges and other commercial varieties. The same bacterium produces, on leaves and twigs, lesions called citrus blast (see p. 546).

The spots or pits usually start with thorn pricks or other injuries to the rind in wet weather. The spots, ¼ to ½ inch in diameter, are light brown to dark brown at first, finally becoming black (fig. 179, *B*).


Fig. 179. *A*, blast on navel orange foliage; and *B*, black pit on lemons; both caused by *Phytomonas syringae*.

In California, black pit is occasionally troublesome on lemon fruits in moist localities, after heavy winter winds with rain, but outbreaks have not usually been severe enough to call for control measures in the orchard. Windbreaks or other means of preventing injury to the fruit in winter would largely control it. Fruits badly affected may also open the way to other kinds of decay and should, of course, be discarded. Small spots, however, that are dry, hard, and firm may not necessarily be subject to other decays so long as the fruit is dry. A severe form of the trouble was described by Smith and Klotz (1945) and Klotz (1946*a*).

### BACTERIAL SPOT OF SOUTH AFRICA

In South Africa, dark spots on fruits and lesions on stems occur which closely resemble black pit and blast in California, but they are caused by a different bacterium, *Bacillus citrimaculans* Doidge. This organism has also been reported in Italy by Sereni. The spots as described by Doidge are either leathery in texture or quite hard. As in black pit, an injury is usually seen at the center of the spot. The spots vary in color from light or dark brown to blackish brown.

### ANTHRACNOSE SPOTS

Anthracnose is a term used to describe lesions in citrus that are produced by fungi such as *Gloeosporium limetticolum* Claus., *G. foliicolum* Nish., and *Colletotrichum gloeosporioides* Penz.; several different forms of spots, decay, or markings have been thus designated (see p. 540). On young lime fruits, *G. limetticolum* produces severe effects resulting in pitting, distortion, or scab. *G. foliicolum* produces an Anthracnose spot on tangerines and Satsuma oranges in Japan. On other varieties of fruits, usually in their mature stage, certain strains of *G. gloeosporioides* produce surface stains, dry, hard spots, and soft rotting.

*Anthracnose of lime fruits.*—This form of Anthracnose, produced by *G. limetticolum*, occurs mostly in moist tropical countries, as in southern Florida and parts of the West Indies. The same fungus attacks leaves, twigs, and blossoms (see fig. 184, p. 541).

On young, rapidly growing fruits the effect varies from shallow spots to deep, depressed cankers. The flower buds, when attacked, turn brown and fall off before opening. The corky, scablike effects should not be confused with scab. Control of Anthracnose on limes may be effected only by protecting the new growth and developing fruit by the use of bordeaux mixture or lime sulphur. Complete control, as pointed out by Fulton (1925), lies in the direction of substituting types of limes which are immune.

*Anthracnose of Satsuma oranges.*—In Japan an anthracnose caused by *Gloeosporium foliicolum* has at various times affected Satsuma oranges. A small, brown spot occurs which spreads quickly, the center becoming light grayish and the advancing edges dark brown or black. The spots vary in size from one-twelfth inch to two inches in diameter. For conditions in Japan, Lee (1923*b*) suggests pruning out the affected twigs which are sources of infection, and spraying with preventive fungicides.

*Anthracnose of oranges, grapefruit, and lemons.*—Besides the forms of Anthracnose already mentioned, there occur in the rind of oranges, grapefruit, and lemons, certain dry, hard spots with which the fungus, *Colletotrichum gloeosporioides* Penz. is associated. (See "Anthracnose Rot," p. 514.) In Florida and California these are often known also as "withertip" spots. They are frequently so similar to spots caused by Alternaria, and even to spots produced by other agencies, that it is difficult to distinguish one from another. Sometimes both fungi occur in the same spots.

The spots usually develop slowly on mature fruits into hard, depressed, brown patches, usually affecting only the rind but occasionally extending into the membranes beneath. On very ripe fruit they may at times develop into the Anthracnose rot described on page 514. The brown or dark brown spots may be regular or irregular in outline and very small to very large in size. They usually start from slight injuries of some kind to the skin of the fruit. An effect on the surface of the rind is known as tear stain.

Only general suggestions can be made for the prevention or control of Anthracnose spots, since they quite often follow unavoidable injury to the rind. Sanitary pruning out of dead branches, so far as this is economically feasible, will reduce the sources of infection.

Means of prevention are indirect: employment of such cultural methods as will produce strong, vital fruits, and avoidance of extreme shocks or injuries to the fruit. Picking the fruit before it is overmature may also help to prevent the injury.

### ALTERNARIA SPOT

Some strains of Alternaria similar to *Alternaria citri* Ellis and Pierce may produce spots and pits as well as rot on mature fruit consequent to injuries. It may also produce a leaf spot (Ruehle and Kuntz, 1937). The breaking down of the tissue is seldom deeper than the thickness of the peel. As the spots develop they change from light brown to dark brown to almost black. Sometimes, in very mature fruit, the fungus may advance from these spots along the membranes of the pulp, finally reaching the center. The spots are not easily distinguished from Anthracnose spots, and frequently both Alternaria and Anthracnose fungi are present in the same spot.

### CYTOSPORINA SPOT

A spot produced by *Cytosporina citriperda* Camp. occurs on mandarin oranges in Italy, affecting the rind and the divisions beneath. The spot is at first slightly depressed, 1/3 to 3/5 inch in diameter, reddish brown, later turning black. As the spots develop, the rind and the walls of the pulp segments beneath it are reduced to a black pulpy mass which extends into the flesh of the fruit.

### OLEOCELLOSIS, OR RIND-OIL SPOT

Oleocellosis is caused by the action of oil liberated from oil glands of the rind. One type, called "green spot," develops on green lemons in which oil is liberated by injury sustained at picking time. As the fruit colors in curing, the areas acted upon by the oil remain green while the rest of the surface colors.

On fruits already colored the liberated oil causes similar effects on the rind without the green color. In California, oleocellosis is seen most often on lemons, but oranges picked too early, when immature or turgid after rains or cold weather, may also be severely affected. The action of the liberated oil causes a slight sinking of tissue between the oil glands in the rind, leaving them standing out prominently (fig. 174, top). The action of the oil is rapid; as little as 0.01 cubic centimeter of lemon oil acting for 1 second is sufficient to produce an effect. Oleocellosis may also follow leaf-hopper injury, as has been observed especially by citrus growers in Tulare County, California.

Prevention of oleocellosis consists in avoiding the conditions which contribute to the escape of oil from glands: (1) Avoid picking fruit when it is wet with rain or dew. (2) Avoid rough handling that would liberate oil, especially when fruit is turgid in cool weather early in the season. (3) Avoid emptying turgid fruit too soon after picking into the hot water of the washing tank (oranges should be held 1 to 3 days, and lemons 3 to 7 days, depending on degree of turgidity after picking, before they are subjected to washing solutions at 115° to 120° F.). (4) In areas where leaf hoppers are active, spray navel trees about October 15 and Valencias the first week in November with whitewash, 25 pounds of lime to 100 gallons of water. If preventive measures for Septoria spot are also desired, add 2 pounds of copper sulfate and 5 pounds of zinc sulfate to 100 gallons of the whitewash.

## WATER SPOT

Water spot is a nonparasitic breakdown of the rind of citrus fruits, the most important factor in its origin being the imbibition of external water by the white portion (albedo). After fruit-rotting organisms enter and cause breakdown, it is called water rot. It is most troublesome on navel oranges that mature in the rainy season. Eastern Los Angeles County and southwestern San Bernardino County, in southern California, are the localities where the navel crop is most severely affected—losses of 50 to 60 per cent for some orchards.

The spot first appears as an elevated blisterlike area on the rind surface. In the blister, minute cracks form which rupture the cuticle and several layers of underlying cells, providing ready entrances for more water and extension of the affected areas. The spongelike capillary structure of the rind and the water-attracting properties of its cells are important in the development of the malady. The internal liberation of the toxic rind oil and decay by blue and green molds are important secondary factors.

The spots first appear in three places: in and around fresh wounds, in the area surrounding the navel, and in the collar portion around the button. Old calloused wounds, of whatever origin, have no effect on the inception of the disease. Mineral-oil sprays, by softening and increasing the permeability of the fruit, increase the incidence and severity of water spot. For details of water spot and water rot see Woglum *et al.* (1927–1932), Fawcett, Klotz, and Haas (1933), Ebeling and Klotz (1936), Ebeling, Klotz, and Parker (1938), Klotz and Basinger (1938*a*, 1938*b*), Turrell and Klotz (1940), Klotz (1938, 1939), and Klotz and Turrell (1939).

*Control.*—Early picking of the crop, where feasible, to avoid overmaturity; employment of orchard heating, windbreaks, and careful orchard practices to avoid fruit injury; control of orange worms; use of cyanide fumigation, or, if practicable, use of only low dosages of mineral-oil sprays with toxicants for insect control, are important in decreasing loss from water spot.

### BLACK SPOT

Black spot caused by the fungus *Phoma citricarpa* McAlp. has been known for a long time in Australia and has also been found in China and Formosa, and recently in South Africa. It is not known in the Western Hemisphere. The disease has been observed mostly on fruits of sweet orange and mandarin orange, but sometimes on lemons.

Small reddish brown spots appear on the surface of the fruit, later turning darker and sometimes becoming black. They vary in size from 1 to 10 millimeters in diameter. As the spots mature, a reddish brown raised margin forms and the light tan or brown centers sometimes become depressed. The spot may extend into the tissue of the rind from 1 to 2 millimeters.

In New South Wales it is recommended to spray with bordeaux mixture (8-5-100 with one-half of one per cent oil) (1) just as the petals begin to fall, (2) six to eight weeks later, and (3) six to eight weeks after the second spraying.

### CITRUS-CANKER, OR CANCROSIS A

Canker produced by the bacterium *Phytomonas citri* Haase is not known at present in either California or Florida. A few infected trees may still be found in isolated areas in Louisiana and Mississippi, but these are rapidly being eliminated. The eradication of canker in Florida and South Africa after it had become well established, and in spite of great difficulties, is perhaps one of the most remarkable of all achievements in plant-disease control. Eradication was accomplished by spraying the trees and surrounding soil surfaces with kerosene and burning. To prevent spread of the malady from grove to grove, workmen's clothing and tools were disinfected with corrosive sublimate after each contact with canker.

Canker occurs in many Oriental countries, including India, Thailand (Siam), Indo-China, Java, China, Japan, and the Philippines. A false canker, or cancrosis B, occurs in Argentina and Paraguay (see below, p. 529). The susceptibility of varieties and species to true canker, cancrosis A, appears, from higher to lower, to be about as follows: grapefruit, trifoliate orange, limes, sweet oranges, lemons, and Satsuma oranges; tangerines and citrons, although slightly susceptible, are not appreciably damaged.

Canker lesions on fruit consist at first of spongy eruptions of tissue in the rind, usually showing a glazed, oily-appearing margin and lacking the yellow halo seen on affected leaves (fig. 180, top). They often show on fruit a crater-like appearance. On leaves, the lesions are small, spongy eruptions, at first white, later becoming tan in color. A margin appears which becomes watery, glazed, greasy, and yellowish brown or green in color. Beyond this is a halo of yellow shading off into the normal green (fig. 180, bottom).

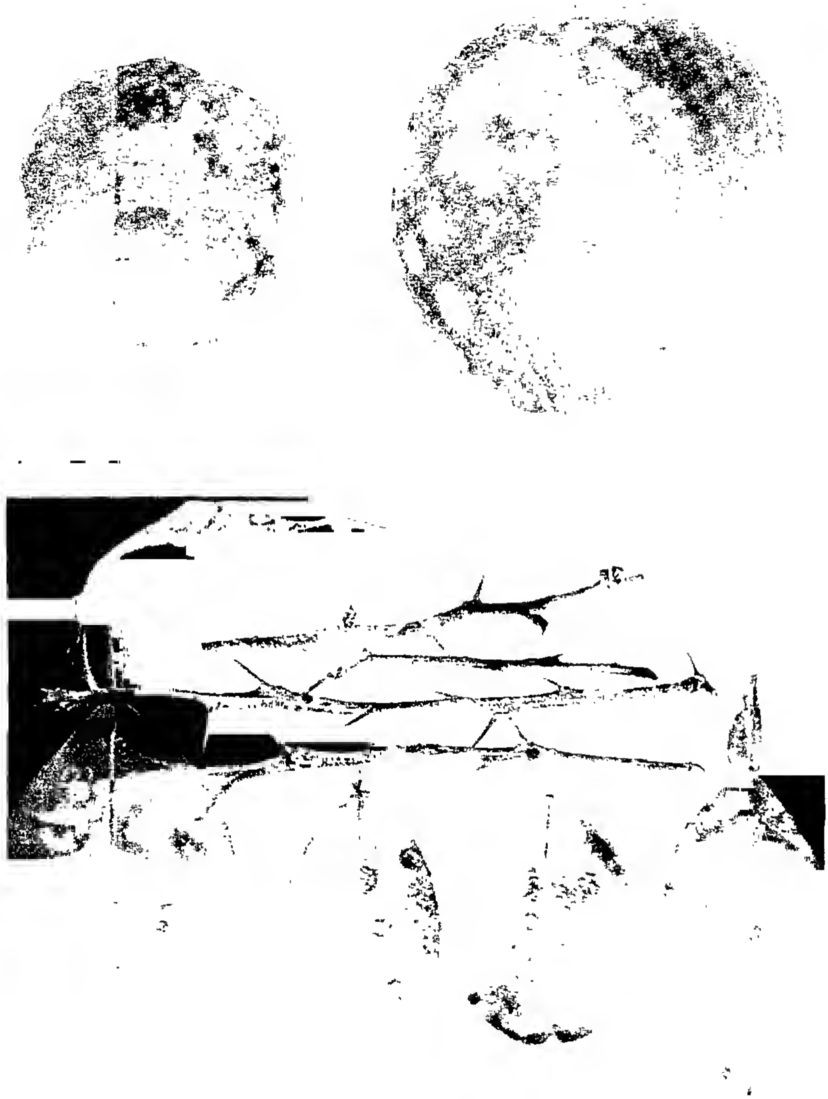


Fig. 180. Citrus canker or cancrosis A, caused by *Phytomonas citri* on grapefruit. Photograph from specimens collected and preserved in Florida before eradication of canker.

In commercially important citrus-producing countries where canker is not known, strict quarantines to prevent its introduction are usually now in force. In citrus countries where canker is already established, resistant species and varieties may be grown.

A measure partly effective in preventing canker on susceptible varieties is spraying, during the first three months after the fruit is formed, with bordeaux mixture containing an excess of lime.

### CANCROSIS B, OR FALSE CANKER

This disease was first known on lime leaves from Paraguay, sent by G. L. Fawcett in 1932 (G. L. Fawcett, 1933). The disease was later found also in Argentina and called cancrosis B by Fawcett and Bitancourt (1940*a*). It has not been found elsewhere. The lesions (fig. 181) have a superficial resemblance to the true citrus canker, cancrosis A, but the host range of the disease is different. Cancrosis B was not found on grapefruit or sweet orange, the varieties badly attacked by the cancrosis A of the Orient. Cancrosis B in Argentina and Paraguay was found, on both leaves and fruit, only on sour orange, lime, citron, and lemon. It appeared to be most common on a lime similar to the West Indian lime. Bacteria were isolated from these cankers, but further study is needed to determine their pathogenicity and the relationship to cancrosis A.

On a lime similar to West Indian lime at Corrientes the lesions were promient on leaves, stems, and fruit. On leaves the lesions appeared first as a halo surrounding the base of a yellowish projection and showing on both sides of the leaf; later they were broken and spongy, some of them crater-like and dark brown. Older lesions were darker, with more cracks.

### CITRUS SCAB

Scab on citrus occurs in three forms: (1) sour orange scab, caused by *Elsinoe fawcetti* Bitancourt and Jenkins; (2) Tryon's scab (Australian citrus scab), caused by *Sphaceloma fawcetti* var. *scabiosa* Jenkins; and (3) sweet orange fruit scab, caused by *Elsinoe australis* Bitancourt and Jenkins. (See Fawcett, 1936, for citations.)

*Sour orange scab, or verrucosis.*—The sour orange scab, first reported in Florida in 1886, has become prevalent in many damp regions, but has never spread into certain dryer climates as represented in California and Palestine, nor into the Mediterranean region. In South American countries it entered after the sweet orange fruit scab. Scab is found on leaves and twigs (fig. 182, *A* and *B*) as well as on the fruit (fig. 182, *C*). On fruits the lesions appear either as corky projections with distinct distortion of the fruit, such as are frequently seen on lemons, sour oranges, and Satsumas, or as slightly raised scabs without much final distortion, as in certain varieties of grapefruit. On young grapefruit, lesions may be greenish to pale yellowish. On sour orange fruits they may be pinkish buff; on Satsumas, various shades of red. The surface of large lesions may become broken into small fine scabs which may sometimes resemble scurf resulting from other causes. Lesions are

first seen as minute dots, which become raised protuberances, more conspicuous as the fruit enlarges, and some may result in abnormal outgrowths on the apices of which the scabby tissue appears. On leaves the sour orange scab is manifested by circular to irregular wartlike projections. Leaves of susceptible

Fig. 181. False canker or chancrosis B on lemon from Argentina. (Photograph courtesy of Dr. A. E. Jenkins.)

varieties become distorted and stunted. The spots frequently become depressed on one side and raised on the other. Large, irregular, corky scabs may also form. Young lesions are often salmon buff or flesh ocher. Central areas are drab or dark olive gray. Old lesions on grapefruit leaves are often pinkish or rose-colored, presenting a smooth, scarred appearance, and as the leaves harden the lesions become rough, corky, and wartlike, changing to a tan color. On twigs of the most susceptible varieties, small, slightly raised warts of the same general appearance as that on leaves are formed.

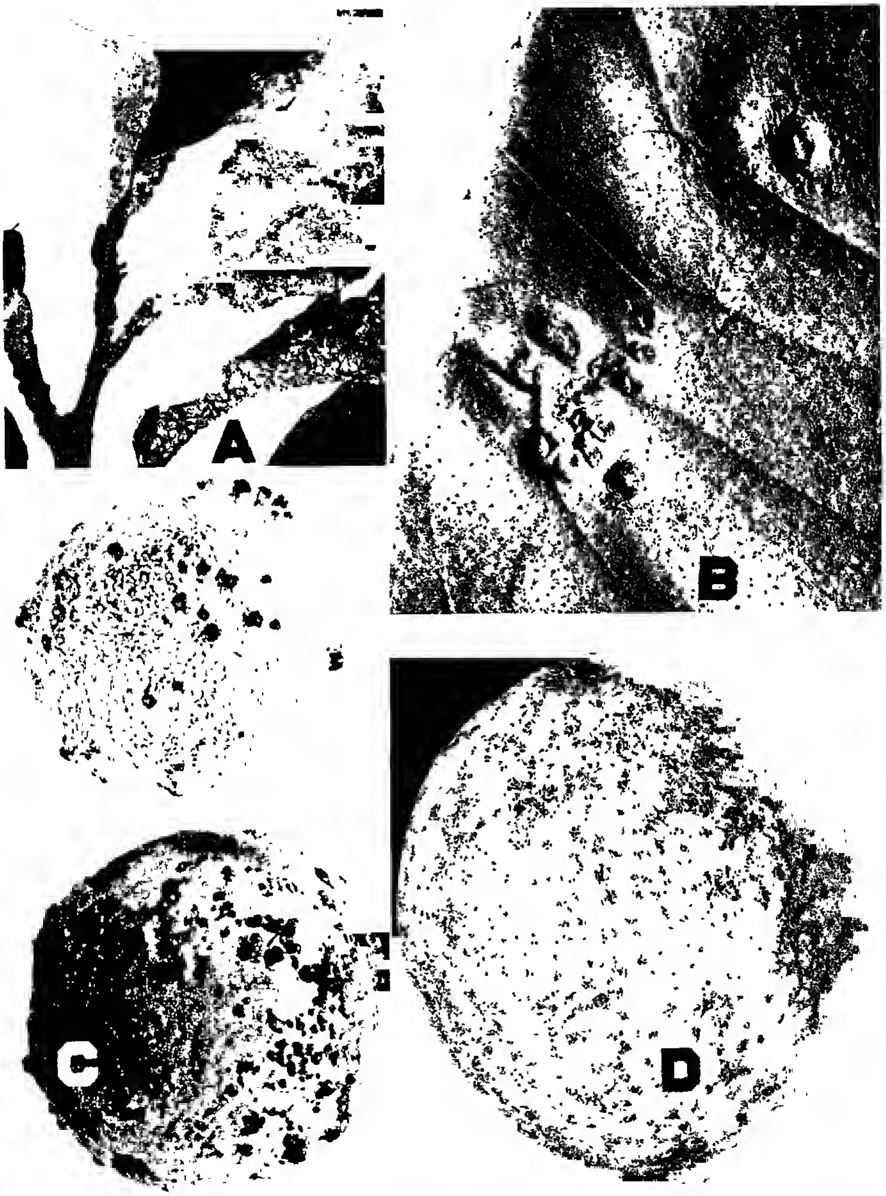



Fig. 182. Sour orange scab caused by *Elsinoe fawcetti: A* and *B,* on foliage; *C,* on Temple oranges; *D,* sweet orange fruit scab caused by *E. australis.* (Photograph D, courtesy of Dr. A. E. Jenkins.)

This scab has been reported on at least twenty-eight varieties and hybrids of citrus. The susceptibility and resistance among the important commercial varieties and species are as follows: sour orange, common sour lemon, and tangelo are severely attacked; King, Satsuma, tangerine, grapefruit, trifoliate, sweet lemon, and Rangpur lime are moderately attacked; oval kumquat, Perrine lemon, Tahiti lime, and Cuban shaddock (Cuban lemon) are rarely attacked; citron, Mexican lime, sweet orange (usually), Royal and Triumph grapefruit, Cleopatra mandarin, and round and Meiwa kumquat are apparently immune.

*Tryon's scab (Australian citrus scab)*.—This scab occurs in Australia and New Zealand. It was reported by Tryon as "yellow rough scab" as early as 1876. He referred the causal agent to *Ramularia* sp., and McAlpine later named it *Ramularia scabiosa*. On both fruit and leaves this scab is similar in general appearance to the preceding type, but appears to differ principally in showing a more crater-like or cupped appearance of the scabs, especially of leaves.

*Sweet orange fruit scab*.—This scab, the perfect stage of which was found to be *Elsinoe australis* by Bitancourt and Jenkins (1937), especially infects sweet orange varieties. It has been found in Brazil, Argentina, Paraguay, and Uruguay, and the earliest record is that of a specimen collected in 1882. That it is different from sour orange scab was first definitely reported in 1931 by G. L. Fawcett, although he had seen it on sweet oranges as early as 1915. The sweet orange is the most important variety attacked, but it has been found on many other species and varieties: tangerines, Satsumas, mandarins, sweet and sour limes, Nagami kumquats, one grapefruit variety, pointed-leaf papeda, and some varieties of tangelos (Fawcett and Bitancourt, 1940*a*).

The sweet orange fruit scab rarely attacks any part except the fruit; as described by Bitancourt (1934, 1935), the fruit has irregular or round corky excrescences, yellow or a clear chamois color, usually 1 to 3 millimeters in diameter, but frequently confluent and covering a large part of the fruit (fig. 182, *D*). The lesions are, as a rule, more rounded, less spongy, and more compact, and on tangerines more flattened and less wrinkled than those of sour orange scab. Only a few leaves have been found affected.

*Scab control*.—The methods of control of the three types of scab are nearly the same. It has been best worked out for sour orange scab in Florida as follows.

Prevention when the disease is likely to be severe consists in (1) spraying with bordeaux-oil emulsion (6-6-100 plus 1 per cent of heavy oil) just before growth starts in the spring, and (2) spraying a second time when at least two-thirds of the blossoms have fallen. This second spraying will also serve to control early melanose. When scab is not likely to be severe and melanose is not a factor, lime-sulfur solution, 3 to 4 gallons per 100 gallons of water before the growth starts and 2½ gallons per 100 for use later, is recommended. Sour orange or Rough lemon trees or sprouts of such varieties affected by sour orange scab in close proximity to grapefruit or other susceptible trees should be removed. Nursery stock is protected from scab by frequent spraying with

bordeaux mixture and in some climates by growing the trees in the shade (Ruehle and Thompson, 1939).

The reference above to sour orange and Rough lemon sprouts would not necessarily apply to sweet orange fruit scab, since it is rarely found on leaves. It is suggested for sweet orange fruit scab in Brazil to spray with bordeaux when fruit is very small, 15 to 30 days after petals fall. In places, where this scab is severe the treatment may be repeated twice at intervals of one month.

### MELANOSE

Melanose is caused by the same fungus, *Diaporthe citri* (Faw.) Wolf, that induces a stem-end rot of citrus fruits and generally appears in shell-bark lesions on lemon trees. It is an important disease in Florida and in certain countries having abundant summer rainfall, but is of minor importance in California or in countries having dry summers. Most commercial varieties of citrus are susceptible, but the disease is most noticeable on grapefruit because of the smoothness of the skin.

Melanose occurs on fruit, leaves, and small twigs. The markings of melanose consist of small, raised, superficial areas, dots, or pustules, made up of gum-filled cells (fig. 183, *A*, *D*, and *C*), often arranged in lines, curves, rings, and irregular-shaped spots. Around the margins and across the surface, lines of breakage give an appearance in miniature of dry, caked mud (fig. 183, *B*). Continuous crusts may form from areas crowded together. Lesions have a waxlike appearance which is amber brown to dark brown to nearly black. To the touch they suggest coarse sandpaper and are thus distinguishable from the smoother rust-mite markings. The pustules often form a tear-streak pattern (fig. 183, *A*), brought about by dew or raindrops, the spores flowing down over the surface.

Preventive measures recommended as a result of experiments in Florida consist in spraying fruit and leaves very thoroughly with bordeaux-oil emulsion (3-4-100 or greater strength plus 1 per cent heavy oil) in April soon after the fruit is set (about 10 to 20 days after the blossoms drop). Pruning out deadwood and twigs harboring the fungus is beneficial, but is not as a rule commercially economical alone (Ruehle and Kuntz, 1940).

### SEPTORIA SPOTS

Several types of spotting produced by species of Septoria fungi have been reported on the fruit and leaves of citrus in various countries. On mandarin oranges in North Africa, black spots 0.4 of an inch or more in diameter occur, which are attributed to *Septoria* sp. On lemons in Italy, *S. citri* Pass. causes spots that range from mere buff-brown specks to sunken, hard, dry, dark brown to black areas covering a third of the fruit surface. The Septoria fungi have also been found on citrus in France, Spain, Portugal, Cyprus, Algeria, South Australia, Victoria, New South Wales, India, South Africa, Brazil, Colombia, Dutch Guiana, and Argentina. In California the fruits of grapefruit, Valencia orange, and lemons grown in the inland citrus areas are commonly affected with *Septoria citri* Pass.; the spotting is less important in

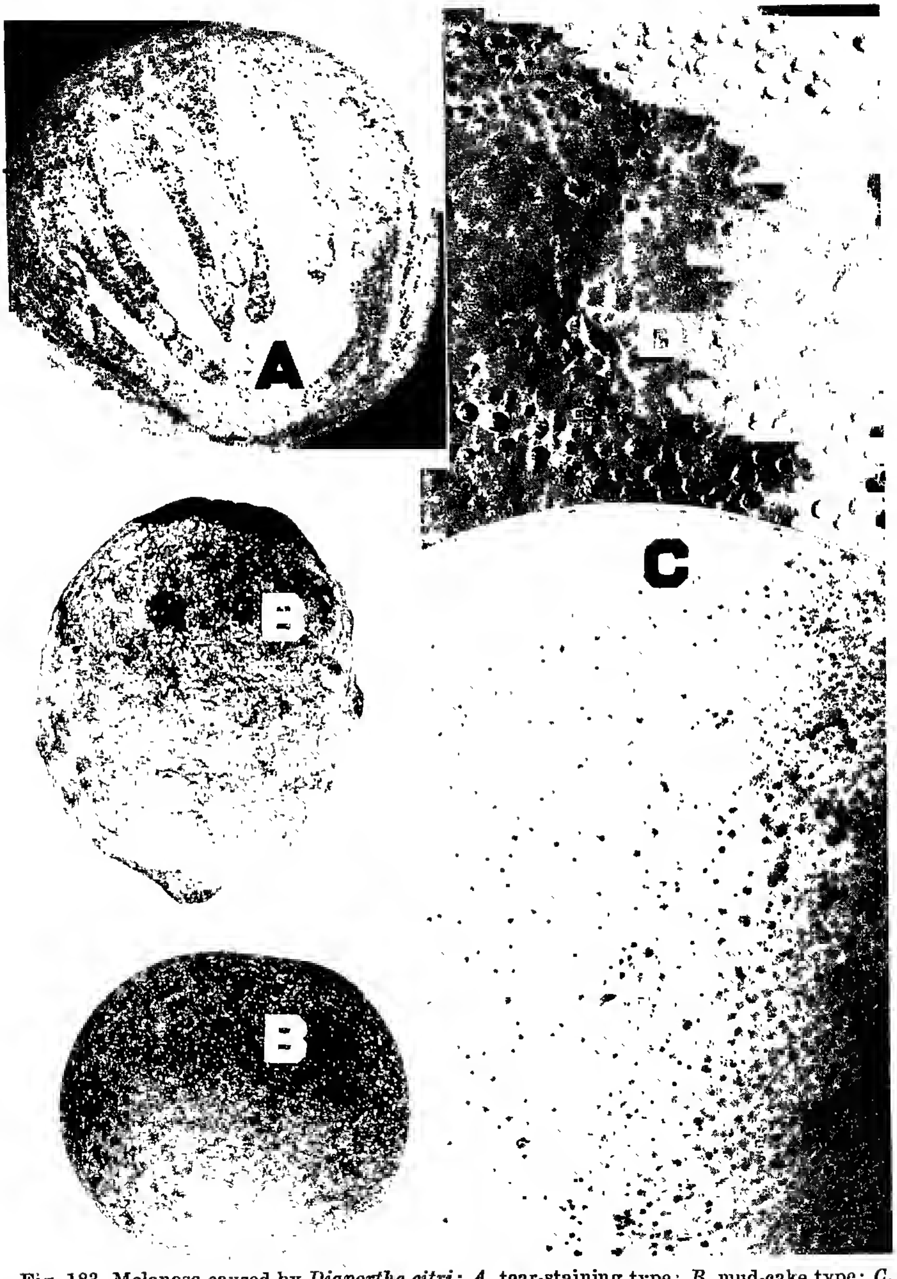



Fig. 183. Melanose caused by *Diaporthe citri: A*, tear-staining type; *B*, mud-cake type; *C*, individual spots, natural size; and *D*, individual spots magnified four times.

coastal groves. Until 1938 the trouble was considered a minor one, but it has since become increasingly troublesome, particularly on grapefruit in Tulare County (Klotz, 1946*b*).

The spots consist usually of small depressions or pits 1 to 2 millimeters in diameter and extending not deeper than the oil glands. The bottom of the pit is usually light tan or buff, with a narrow greenish margin which becomes reddish brown as the fruit matures and colors. Some spots, dark brown in color, may attain a diameter of 4 to 10 millimeters, and may extend into the albedo of the rind. Black pycnidia (spore fruits occurring in certain fungi) may develop in these spots. Another form of Septoria spotting is a tear staining not unlike Anthracnose tear staining, but somewhat coarser in appearance. Frequently, both fungi can be isolated from all types of the spotting.

Control consists in a thorough application of bordeaux mixture or zinc-copper-lime just before the winter rains begin (Fawcett and Klotz, 1940). In groves that are not fumigated a bordeaux mixture made with 3 pounds of copper sulfate ($CuSO_4{\cdot}5H_2O$) and 3 pounds of hydrated lime per 100 gallons (or the commercial equivalent) is used. On trees to be fumigated a more dilute bordeaux is used: 1 pound each of copper sulfate and hydrated lime per 100 gallons; or a zinc-copper-lime spray: 5 pounds zinc sulfate ($ZnSO_4{\cdot}7H_2O$), 1 pound of copper sulfate, and 4 pounds of hydrated lime per 100 gallons. Use of the dilute sprays is necessary because copper makes the tree more susceptible to fumigation injury. The addition of zinc and copper to whitewash containing 25 to 33 pounds of hydrated lime per 100 gallons has also been found effective in checking germination of the Septoria spores. Many of the old standard and the new fungicides have, in laboratory tests, been found capable of preventing germination of spores of Septoria. Preliminary field experiments in Tulare County indicate that sprays of 5 pounds of zinc sulfate, 1 pound of copper sulfate, and 4 pounds of hydrated lime; 1½ pounds of disodium ethylene bis-dithiocarbamate plus 1 pound of zinc sulfate and ½ pound of hydrated lime; 2 pounds of zinc dimethyl dithiocarbamate; 1 pound of cuprous oxide; and 1 pound basic copper sulfate, 1 pound zinc sulfate, 30 pounds of hydrated lime—all amounts being for 100 gallons of spray—may give satisfactory protection to grapefruit (Klotz and Zentmyer, unpublished; Klotz, 1945*b*, 1946*b*; Klotz and Parker, 1945).

## EXANTHEMA

Exanthema, often known in Florida as dieback, is now known to result from copper deficiency. Usual symptoms are: (1) gum pockets at or near the leaf nodes in succulent branches; (2) excrescences of gummous tissue forced through longitudinal or rounded breaks in the bark; (3) stained terminal twigs, the stains being caused by infiltration of a gumlike substance into cells near the surface; (4) brownish, glossy, gum-soaked areas on fruit, often accompanied by splitting of fruit; (5) gum in angles of segments surrounding the seeds. Occasional symptoms are: (1) a deep green tone in the color of the foliage, preceding an outbreak; (2) abnormally thick or coarse, elongated leaves; (3) S-shaped branches; (4) rosette or staghorn growth. It is remedied

by spraying with bordeaux mixture, preferably just prior to or during the flush of growth in which exanthema may be expected; also, less quickly or efficiently, by spreading copper sulfate on the soil, 1 to 4 pounds per tree. (See Vol. I, chap. vii, and "Copper," chap. vii, p. 360, above.)

### SMOKY BLOTCH AND FLYSPECK FUNGUS

Smoky blotch, previously called sooty blotch,[1] which occurs in Florida, Southern Rhodesia, South Africa, and South America, appears as smoky or sooty areas caused by a branching network of dark hyphae on the surface of the rind. In Brazil, smoky blotch is caused by *Stemiopeltis citri* Bitancourt, *Sirothyrium citri* Bitancourt being the imperfect form. In Southern Rhodesia, Bates has found this fungus in company with an unidentified one.

Flyspeck fungus has commonly been attributed to the same fungus as on apple, *Leptothyrium pomi*, but Bates[2] finds three main types on citrus in Southern Rhodesia, one belonging to Microthyriaceae, one to Micropeltaceae, and the third not classified, probably none of which is produced by the apple fungus. The flyspecks occur as black specks made up of a pad of fungus hyphae on the surface.

Smoky blotch on picked fruits may be bleached by dipping them for 30 to 45 seconds in a solution composed of 4 ounces of bleaching powder (chloride of lime) and 3 ounces of sodium bicarbonate per gallon of water. If decay is troublesome, chloride of lime and boric acid may be substituted (Bates, 1939).

### MISCELLANEOUS SPOTS AND MARKINGS ON FRUIT

The miscellaneous spots and markings on fruit named below will not be described here; descriptions will be found in *Citrus Diseases and Their Control* (Fawcett, 1936) at the pages indicated: Exobasidium disease, page 557; wind injury, 340, 558; fumigation injury, 562 (see also Klotz and Lindgren, 1944); spray injury, 565; splitting, 566; creasing and puffing, 570; slug injury, 575; speckling, 575; chemical burning, 576; heat injury, 576; Tricoseptoria spots, 576; thrips injury, russeting, silvering, and buckskin, 572; and frost injury, 474 to 479.

## DISEASES OF TWIGS, LEAVES, AND BRANCHES

The diseases of twigs, leaves, and branches, considered in relation to their effects and the nature of the lesions, may be arranged in four classes:

1. The eruptive diseases, in which the tissue is raised, forming scabs or pustules usually composed of the modification of the host tissues, as in canker, scab, melanose, leprosis, etc.

[1] Bates writes: "In view of the confusion that has existed in the past in regard to the application of the term 'sooty blotch' to both pomaceous and citrus fruits blemishes, and with the further consideration that different fungi are responsible for these blemishes, I have suggested that the name smoky blotch be adopted for the citrus blemish." In Australia the term smoky blotch is already applied to such blemishes on citrus fruits. He adds that *Stemiopeltis citri* (and its imperfect form, *Sirothyrium citri*) has been found on citrus in Southern Rhodesia, but that most of the smoky blotch there appears to be caused by an unidentified fungus. (Letter from C. R. Bates to H. S. Fawcett, January 29, 1942.)

[2] As cited in the preceding footnote.

2. Superficial growths or effects, not composed of the host tissues, such as sooty mold, lichens, and powdery mildew.
3. Necrotic diseases in which there are dead spots of limited extent with sinking and collapse of tissue or extensive death of parts as leaf spots and twig blights.
4. Diseases showing extensive changes in form or color or general effects.

### Eruptive and Pustular Diseases

Citrus canker, false canker, scab, melanose, and exanthema, five eruptive diseases which belong under this heading, have already been described. (See pp. 527, 529, 533, and 535.)

#### GREASY SPOT

Greasy spot, also known as black melanose, is found especially on grapefruit leaves in southern Florida and Cuba. In the Philippines and in Japan it is reported as common on the calamondin orange.

The spot is usually on the under side of the leaf, not much affecting the chlorophyll, but appearing as a dark, slightly raised spot suggestive of a mass of dark grease under a semitransparent epidermis.

This type of spot is considered by Bitancourt in Brazil to be due to the effects of rust mite. Although this appears to be the cause of much of what has been known as greasy spot, similar effects occur in California in areas from which the rust mite is absent.

#### GUM SPOTS

Small raised pustules, brown or dark brown in color, are very common on leaves. Some are about the size of melanose; some may resemble canker; and other lesions and the spots are at times mistaken for infectious disease. They are usually hard and smooth on the surface and often consist of a small area of surface cells impregnated by a hard gumlike material that might be produced by slight frost followed by bright sunshine, slight sunburn, fumigation, injuries from mites, and possibly by spray materials.

### Superficial Coatings, Markings, or Pustules

#### SOOTY MOLD

On the surface of leaves and fruit there may occur a conspicuous black coating known as sooty mold. It is composed of a weft of microscopic fungus threads of several species of fungi, including *Capnodium citri* B. and Desm. It occurs wherever honeydew-secreting insects are found, such as white fly larvae in Florida and black scale, cottony cushion scale, and aphis in California. Although the sooty mold does not attack the tissue, it interferes with the normal function of the tree leaves, and is a sign of the presence of some insect pest.

Since sooty mold occurs merely as a concomitant to the presence of some honeydew-secreting insect, the prevention and treatment consist not in fight-

ing the mold itself, but in exclusion and control of the insects which bring it about. Soon after the insects are eliminated the sooty mold disappears.

### POWDERY MILDEW

Powdery mildew on leaves, produced by *Oidium tingitaninum* Carter is reported as common in Java, Ceylon, and India, on the leaves of various citrus species, and has been found occasionally on tangerines in California.

It is easily identified by white patches which, more commonly than not, occur on the upper surface of the leaves. It does not spread in a perfectly circular manner, but radiates from a center of infection. The tissue between the filaments of fungus mycelium is at first a darker watery green than the normal color, and later loses the green and becomes yellow. The young leaves may shrivel, becoming dry and adhering to the twig. No experiments are recorded for control of mildew on citrus. Sulphur sprays or dusts may be used.

### FELT

A soft, feltlike, almost leathery covering completely surrounding the twigs, produced by the fungus *Septobasidium pseudopedicellatum* Burt, or by other species, is found in moist climates such as those of Florida, Cuba, Brazil, and Formosa. These fungi have been found associated with certain scale insects, the most common insect associate on citrus being *Lepidosaphes beckii* (Newm.). Other species of Septobasidium associated with citrus scale insects in North America are—besides *S. pseudopedicellatum* Burt, mentioned above—*S. conidiophorum* Couch, *S. lepidosaphis* Couch, *S. pedicellatum* (Berk. and Curt.) Pat., and *S. spongium* Berk. and Curt. The surface of the coating produced by *S. pseudopedicellatum* is smooth and compact. Beneath, it is soft and spongy. The entire enveloping cylinder is made up of minute, closely woven, mycelial threads, none of which appear to penetrate the bark. A species of scale insect is found under the coating on the surface of the bark. The fungus probably gives protection to the insects, and they in turn make secretions favorable to the growth of the fungus. The only control usually necessary is to prune out the branches bearing the fungus.

### LICHENS

Lichens are frequently seen on twigs and branches of citrus, especially in moist situations. They are grayish green and paper-like and form small circular to irregular-shaped spots. They are considered harmless so far as any direct injury produced by their growth is concerned, since they obtain their own nutriment from the air or from functionless tissue on the surface of the bark. The presence of lichens on the tree need not cause alarm. If the lichens increase because the tree lacks vigor, it is better to use means of bringing the tree to a vigorous growing condition than to incur the expense of ridding the tree of lichens. They may, however, become so abundant as to be troublesome and harmful in an indirect way by shading the leaves or by harboring other organisms. If so, they may be killed by spraying with a weak bordeaux mixture or a strong lime-sulphur solution.

### ALGA SPOT

A spot produced by a partly parasitic alga, *Cephaleuros mycoidea* Karst., sometimes occurs on leaves and twigs in southern Florida, the West Indies, and elsewhere.

The spots are slightly raised, and circular to irregular in outline. Their surface is covered with reddish brown, hairlike structures. When these are absent, the surfaces of older areas are greenish gray and velvety. The bark may be swollen, and the twigs enlarged at the affected parts, though only a few surface layers of cells are invaded.

Since the alga appears to attack trees of low vitality most readily, an important preventive measure should be to keep the trees in a vigorous growing condition. Spraying with either bordeaux mixture or commercial lime-sulphur appears to prevent effectively the formation of alga spots.

### ENTOMOGENOUS FUNGI

Many fungi parasitic on citrus insects produce pustules or other forms of growth on leaves, twigs, and fruit, and may be mistaken for harmful organisms although they are often beneficial in helping to keep the insects in control. These are discussed in chapter xiii.

## Necrotic Diseases

Necrotic diseases are those that result in the death of an appreciable amount of tissue, either in localized spots or throughout entire parts.

### MAL SECCO

This highly destructive disease has been found in Turkey, Greece, Palestine, and Sicily. When first observed and studied in Sicily about 1922, it was confused with citrus blast, and later with Anthracnose, but the cause was discovered by Petri (1929) to be a wood-invading fungus, *Deuterophoma tracheiphila* Petri. It is now believed that before it occurred in Sicily it had long existed in Greece. In Sicily it first appeared in the vicinity of Messina, whence in about ten years it spread slowly along the coast to orchards in the vicinity of Catania. Later it was discovered in Turkey, where in 1940 it was said to threaten Turkish lemon culture. In Turkey, as in Sicily, lemon, citron, and sour orange were found susceptible, and sweet orange and mandarin resistant, to the malady.

The disease first manifests itself as a sudden wilting and drying of the leaves and twigs, often on one side or in one part of the tree. The leaves may remain attached to the twigs as they dry, or may be shed before the twigs die back. In severe attacks on the lemon, which is a highly susceptible variety, larger branches and finally the whole tree die back after a year or two without any visible lesions on the bark of the trunk. The sudden wilting of leaves and dying back of branches does not alone suffice to identify the disease, since damage from frost, chemical injury to the roots, root rots, and basal rots may show similar symptoms. Other accompanying effects should be looked for. The wood

of the green twigs and branches usually shows a pinkish or reddish discoloration on a slanting cut even before they have wilted or even before the bark has died. The fungus has also been found in the fibrovascular bundles of half-grown green fruits and in green leaves.

The disease at first gives the impression that the branches may have been infected by an organism that has traveled back from the tips of the branches, and this appears not infrequently to be what actually occurs. Petri has shown that, in young plants, infection may be induced through leaves and twigs, and that the fungus thus extends downward in the plant. In Turkey it is considered by Gassner (1940) that the primary infection arises mainly from frost injury to the tips of the shoots. External factors that are thought to intensify the malady are the use of nitrogen fertilizers, "Verdelle" practice, and excessive fruiting.

The most severe and rapidly developing attacks on older trees, however, probably start from infections farther down on the roots or the lower part of the trunk. By careful dissection and examination of large roots and trunks of lemon trees in orchards first showing mal secco, Savastano and Fawcett (Fawcett, 1936) were able to trace, by means of a slight discoloration, a path of infection in the wood up from a root through part of the trunk to certain branches and twigs that showed the first symptoms. That such a method of development is quite possible was also shown by inoculation experiments by the same investigators. Present knowledge offers no satisfactory means of controlling the disease once a tree has become affected.

The apparent resistance of sweet orange and mandarin would suggest replanting with these varieties where trees on sour orange stock have been killed by mal secco. A lemon variety known as Interdonato also manifests resistance to mal secco. If lemons are replanted, trees budded on mandarin or sweet orange rootstock should be used; these would at least have some resistance to the root infection which probably produces the most rapid and severe form of the disease (Fawcett, 1936; Gassner, 1940). Where sour is used, a "sandwich" of sweet or mandarin orange has also been suggested.

### ANTHRACNOSE (INCLUDING WITHERTIP AND BLOSSOM BLIGHT)

Anthracnose is a term used to designate effects produced on citrus by fungi such as *Gloeosporium limetticolum*, *G. foliicolum*, and *Colletotrichum gloeosporioides*. (For effects of these fungi on the fruit see pp. 514 and 524.)

*Anthracnose on limes.*—This disease, *Gloeosporium limetticolum*, causes serious damage to limes in southern Florida, Cuba, and the West Indies. The dying back and withering of the young trees has suggested the term "withertip," and the frequent blighting of buds and flowers, "blossom blight."

Young, rapidly growing twigs are attacked. The twigs wither, and shrivel one to several inches at the tips (fig. 184). Frequently the live parts fall away, with formation of gum at the wound. Young leaves may die, or, at least, dead areas may form on the margins of the tips. The petals of unopened buds turn brown and the buds fall off without opening. Control of this disease has already been mentioned on page 525.

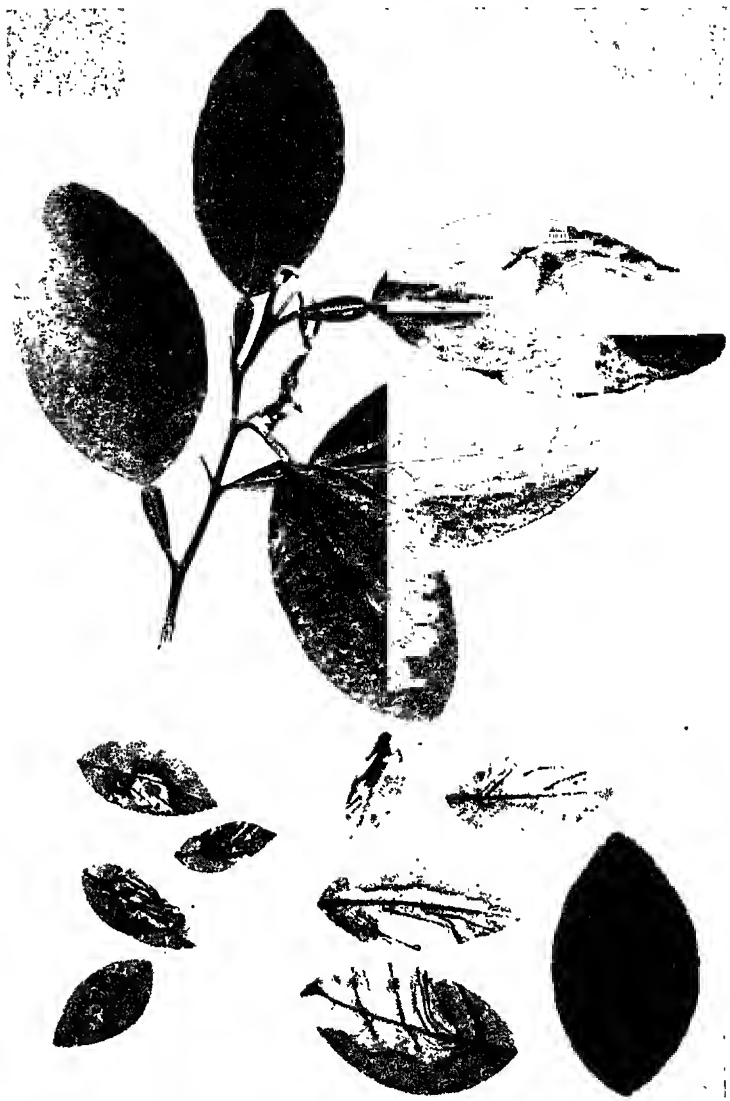


Fig. 184. Anthracnose of lime caused by *Gloeosporium limetticolum*. (After Clausen, 1912.)

*Anthracnose of Satsumas.*—This disease, caused by *Gloeosporium foliicolum*, is not definitely known outside of Japan. Brown spots occur on the young, actively growing trees during May and June. Fallen leaves may show watery, cloudy spots, on which bright-red pustules of the fungus appear.

*Anthracnose of orange, lemon, grapefruit, etc.*—The form of anthracnose produced by certain strains of *Colletotrichum gloeosporioides* is widely distributed in citrus-growing countries. In many respects the fungus associated with it resembles closely the lime anthracnose. There seem to be forms or strains of this fungus, some of which are parasitic and others saprophytic. Forms of this fungus are almost universally present on dead twigs or dead tissue of citrus in Florida and certain localities in California. In general it attacks only the twigs or leaves that have previously been weakened by unfavorable soil, climatic, or nutritional conditions. Since other fungi, such as *Diplodia natalensis,* are often associated with it, certain of its effects are probably produced by a combination of several fungi acting together.

On leaves that are nearly or quite mature, spots occur which at first are light green and later turn brown. In moist weather, dark-colored pustules may show pink spore masses over the surface of the spots. The spots are at the margins or tips of the leaves or, rarely, near the midribs. On branches of varieties other than limes, anthracnose is characterized by the dying back of mature twigs. The dying back is usually slow, but occasionally the leaves wither and dry up suddenly. It is not safe to conclude from the mere presence of Colletotrichum fungus that it is primarily the producer of a given effect. Usually the fungus is unable, apparently, to attack uninjured parts, but enters as a secondary invader after the organ has been injured or killed by some other agency.

Since anthracnose of this type depends so much, for its effective development, on lowered vitality of tree tissues, it is of the first importance to keep up the health and vitality of the trees by applying such fertilization and orchard practices as will keep the trees resistant even when the fungus is present. If the trees show serious symptoms of anthracnose in the twigs, pruning may be necessary to bring them back to health.

### MESOPHYLL COLLAPSE

Leaves of sweet orange in the coastal regions of North and South America frequently show one or more dead areas of various sizes throughout the blade. The surface of a spot on the lower side of the leaf is depressed, leaving veins and veinlets standing out prominently and decreasing the thickness and volume of the affected region (fig. 185). Internally, the cells in the tissues of the spots are dead or dying, some dry out and collapse, others become enlarged. The palisade and epidermal tissues are unaffected in the early stages of the malady, but eventually die and dry following the collapse, death, and drying of the spongy mesophyll below. Fruiting bodies (acervuli) of the Colletotrichum fungus are commonly present on the surface of the spots, but have no apparent part in originating the attack.

The cause of mesophyll collapse (Turrell, Sokoloff, and Klotz, 1943) is as yet unexplained. It has been attributed to red mite injury, water deficiency, and excessive transpiration, but is probably due to physiological or nutritional unbalance. Chemical examination reveals that the ratio of potassium and sodium to calcium is much higher in collapsed than in normal tissue, both

Fig. 185. Mesophyll collapse.

in the aqueous and in the solid phases of the leaf (Sokoloff, Klotz, and Turrell, 1943). This suggests a relationship of cation-pectate complexes to capacity for water retention. Although potassium and sodium pectates have a greater capacity for hydration, they hold water much less tenaciously than calcium pectate, a normal cell constituent.

### AREOLATE SPOT, OR MANCHA AREOLADA

This is a leaf spot of striking appearance found in Brazil, Venezuela, and Surinam (Dutch Guiana). It is produced by a fungus now judged by Rogers (1943) and by Rogers and Jackson (1943) to be *Pellicularia filamentosa* (Pat.) Rogers, originally described by Stahel (1940) in Venezuela as *Corticium areolatum*[1] Stahel.

The areas are light-colored, with concentric partial rings or bands (fig. 186). There often occur along the darker rings numerous fruiting structures of the common saprophytic fungus, *Leptosphaeria bondari* Jenkins and Bitancourt, which was at first mistakenly considered to be the causal organism by Bondar in 1929. Bondar (1929), however, had mentioned a fungus in association with the spot, which he called *Oidium citri* Bondar. This was probably the true fungus. It was known in Brazil as mancha areolada.

According to Stahel (1940), the sour orange used for stock suffers most; grapefruit, mandarin, and some kinds of oranges are also susceptible. The common sweet orange is fairly resistant, except when grown in heavy shade. In Surinam no spots have been seen on lemon, lime, and kumquat. Spots may be found on young twigs, but have not been seen on fruits.

In Surinam, in nurseries, the disease was effectively suppressed by collecting and burning all spotted leaves. In both Surinam and Brazil a spray of bordeaux mixture is suggested as a control measure.

### CORTICUM BLIGHT IN PANAMA

On sour orange seedlings collected in Panama in May, 1937, a fungus later judged to be probably a variety of *Corticum solani* Prill. and Del.,[2] was found producing a mildew-like growth on the leaves and causing dead spots. The spots did not show the concentric rings characteristic of the areolate spot. In examining the fungus, Stahel[3] reports that the hyphae are similar to those on the areolate spot but that the side branches are strangely curled and not so heavily swollen as those of the South American fungus. Because of these differences and the striking difference in symptoms the present authors believe it to be a fungus different from *Pellicularia filamentosa* but closely related to it.

### THREAD BLIGHT

This disease, attributed by some investigators to *Corticium koleroga* (Cooke) Höhn, and by others to *C. stevensii* Burt or to both species,[4] occurs in tropical or semitropical countries and has been reported on citrus in Florida, the West Indies, and Argentina. *C. koleroga* attacks coffee in Puerto Rico, Jamaica, Trinidad, Surinam, Venezuela, and Colombia. The fungus forms its mycelium

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[1] This name had previously been used by Bresadola (1925) for a different fungus on *Alnus*.

[2] Identified by Miss Wakefield, Kew Gardens, London; letter of April 4, 1939, to H. S. Fawcett. Rogers (1943) identified this fungus as the same species, *Pellicularia filamentosa* (Pat.), as that causing areolate spot. The spots, however, are very different in appearance from areolate spots.

[3] Letter from G. Stahel to H. S. Fawcett.

[4] According to Rogers and Jackson (1943) both would be *Pellicularia koleroga* Cooke.

Fig. 186. Areolate spot caused by *Pellicularia filamentosa* (Pat.) Rogers (*Corticium areolatum* Stahel) from Surinam. (Photograph courtesy of G. Stahel.)

in slender strands which are nearly uniform in diameter, whitish at first, finally becoming dark brown. The mycelial threads extend along the branches, midrib, and veins of the leaves, branch out between the cells of the leaf parenchyma, and come to the surface on the upper side of the leaf, forming minute pustules which give a speckled appearance to the leaf. These separate spots then grow together into a thin membrane of a smoke gray color covering the entire surface of the leaf. Death of the twigs and leaves results.

An effective control of thread blight, reported by Nowell (1923), is to spray with bordeaux mixture prepared with an excess of lime. Spraying with lime-sulfur is reported as ineffective.

## CITRUS BLAST

Citrus blast, caused by a bacterial organism, *Phytomonas syringae* (Van Hall) Bergey, was first thought to occur only in northern California, but has now been found in certain parts of Australia, Palestine, Sicily, and South Africa. Black pit, which has already been described (p. 522), is produced by the same organism. The activity of citrus blast, under California conditions, usually extends over not more than six to eight weeks in the moist winter and spring. Oranges and grapefruit are probably more susceptible to attacks of the disease on leaves and twigs, and lemons to attacks on the fruit. (For a history of the investigation of citrus blast and black pit see Fawcett, 1941*b*.)

Citrus blast usually starts in a break or a torn place on the wing of the petiole and extends rapidly in both directions at the base of the leaf blade and to the twig at the base of the petiole (fig. 179, top, p. 523). The affected area on the twig, around the base of the petiole, is at first brown to black; later it changes to reddish brown, forming definite scabs as the disease runs its course. Lesions on larger twigs may be auburn or mahogany red. If the blast progresses rapidly, the leaves wither and die while still attached, but if its progress is slow an abscission layer is formed and the leaves are shed.

Experiments have shown that a large part of the effects of the disease may be prevented, under California conditions, by spraying the trees thoroughly with bordeaux, if this is done not later than the first of November. Spraying just before the usual outbreak of the disease, which occurs in December or January, seems to be of little value. Since the severe effects of the disease, however, usually come only on an average of once in three or four years, it has not been found profitable to spray every year.

The suggestions for treatment are to use methods of soil fertilization, irrigation, and culture that will insure a good healthy growth of the leaves before the rainy season sets in. An untimely autumn growth which does not have time to harden before the cold winter is especially susceptible. Protection from winds is also advantageous. Nursery trees may be protected by spraying with bordeaux mixture 6-6-100.

## BACTERIAL LEAF SPOT OF SOUR ORANGE

This leaf spot was first found in sour orange nursery trees in Uruguay in the vicinity of Salto in 1937 by Fawcett and Bitancourt (1940*c*). Later it was

reported in Argentina. Its effect on some trees appeared to be injurious. The spots were usually in places where the leaf tissue was injured by scratching. Along a small thorn scratch on the epidermis a series of spots occurs, each with its center on the line of injury. The spots are 0.5 millimeter to 6 millimeters in diameter, more or less round, with definite, slightly wavy margins. They are raised somewhat at the periphery and depressed in the center. The smaller ones are waxy, and have an amber color; the larger ones show concentric regions as if they had enlarged in two or three stages. A chlorotic halo surrounds the spots. In transverse sections, Bitancourt (Fawcett and Bitancourt, 1940*c*) found that the tissues in the spots are full of bacterial aggregations which occupy the much enlarged intercellular space of the spongy parenchyma.

The disease should not be confused with either cancrosis A or cancrosis B, both of which form corky eruptive lesions on leaves.

### PINK DISEASE

Pink disease, produced by *Corticium salmonicolor* Berk. and Br., is a tropical disease not only on citrus but on many other plants such as rubber, cacao, coffee, and tea. Its first appearance on branches of citrus is usually a slight gumming. The bark seems dry and hard, adhering closely to the wood, and longitudinal cracks often appear at the same time as the gumming. The pustules, 1 millimeter or less in diameter, are dirty white to pinkish in color. The mycelium of the fungus grows over the surface of the branch, forming an orange-pinkish incrustation which, at first smooth and velvety, later becomes roughened and broken up into patches. As the disease advances, the bark may become a dry mass of shredded fibers running longitudinally with the branch. Stoppage of the water conduction and wilting of the leaves and death of affected limbs are the final effects. If the trunk is girdled, death of the entire tree may result.

Effective control, by pruning out affected limbs with proper disinfection and followed by spraying, has been obtained in experiments by Lee and Yates (1919). Either lime-sulphur or bordeaux oil emulsion spray may be used.

### DIPLODIA TWIG BLIGHT

Diplodia twig blight, caused by the fungus *Diplodia natalensis* Evans, occurs in various tropical and semitropical countries. The fungus also causes Diplodia rot (p. 515) and Diplodia gummosis (p. 557), and may combine with Phomopsis in shell bark (p. 558).

The dying of the twigs begins at the tips and extends for some distance, ending in a sharply defined line, where more or less gum is usually formed. Sometimes no limiting line develops until the entire twig or part of a branch or trunk is enveloped. On the bark are reddish brown dead areas and minute black pustules indicating that the Diplodia fungus is present.

Since Diplodia twig blight often follows unfavorable conditions of tree health, the tissues being low in vitality, proper fertilization and care of the trees to keep them in vigorous condition is usually beneficial. In the West

Indies, planting in closely sheltered places to preserve moisture, and providing windbreaks in all exposed locations, have been suggested as measures of prevention.

### SCLEROTINIA AND BOTRYTIS TWIG BLIGHT

(See also Cottony rot, p. 511, and Botrytis rot, p. 512)

Both of the twig-blight fungi, *Sclerotinia sclerotiorum* and *Botrytis cinerea,* produce similar effects on twigs. They may start in the end of the twig or in the blossoms and spread back for short distances, or may start farther back on a twig or limb, girdle it, and cause the distal portions to wither and die suddenly. Both of them cause the bark to assume a shredded fibrous condition as it dies (fig. 176, *B*, right).

In Sclerotinia twig blight, black, flattened sclerotia sometimes develop in and under the bark on the twigs. The bark at first is soft, gum exudes, and the invaded bark dies and assumes a light buff color. The Botrytis twig blight is usually not so light in color as the other and rarely, if ever, forms black sclerotia, but instead may show a gray, furry growth in moist weather, owing to the fruiting of the fungus.

These blights, although conspicuous at times, are usually of minor importance, and as soon as warm dry weather occurs their growth is entirely arrested. If they become serious, the diseased twigs may be cut out and destroyed to prevent their being a source of infection.

### FUSARIUM TWIG DISEASE

(See also dry root rot, p. 564)

A wilting and dying back of twigs, frequently accompanied by exudation of gum, has been studied in Egypt and shown to be produced by the fungus *Fusarium solani* (Mart.), which is found also in South Africa and Honduras.

Leaves suddenly wilt and are shed, and small terminals wither and die back from the tips. At the base of the dead part, the bark splits, is slightly raised, and gum often oozes in appreciable amounts. Gum may also form in scars left by the fallen leaves. Sometimes the exudation of gum is absent.

The control measures suggested are avoidance, as far as is possible, of injuries to the twigs, avoidance of conditions that tend to weaken the tree, and cutting out the diseased twigs five to six inches below the infected part and disinfecting the cut ends.

### ASCOCHYTA DISEASES

Diseases caused by several species of Ascochyta occur in New Zealand, Australia, Sicily, and Brazil.

*Bark blotch.*—This disease is caused by the fungus *Ascochyta corticola* McAlp. in Australia and New Zealand. On stems and branches, dark brown bark areas surrounded by raised margins occur. Gumming usually accompanies infection. In four to six months, grayish white patches appear in which are minute black bodies (pycnidia) of the causal fungus. Treatment consists in removing the diseased tissue and disinfecting with acidulated mercuric chloride or bordeaux paste.

Other species of Ascochyta also occur in Australia. *A. cineria* McAlp. produces ashy gray patches on twigs; *A. citricola,* spots on twigs and leaves.

*Ascochyta twig blight and leaf spot.*—The fungus *Ascochyta citri* Penz. produces blighting of twigs in Cyprus, spotting of leaves in Italy, and both blighting of twigs and spotting of leaves in Brazil. The spots on leaves are nearly circular, dark brown, and eventually become grayish. Young as well as mature leaves are attacked, turn yellow, and drop. Young twigs are killed back.

*Ascochyta hesperidearum* Penz. on leaves in Sicily and an unidentified species in wood rot in California (Fawcett, 1936) have been reported.

### BUD-SHOOT WILT

Shoots from inserted buds frequently wilt, become limp, bend down, and finally die. In 1945 it occurred most commonly on Sampson tangelo rootstock. Halma (1941) records observing it in California in 1930.[1] He noted that 85 per cent of wilt studied during one season was on shoots less than 6 inches in length, and that none occurred on shoots exceeding 18 inches in length. There almost always developed a second shoot which did not wilt. Sudden rises in temperature and desiccating winds were observed to be important factors. Halma believes that incomplete union of inserted buds prevents enough water from entering when sudden hot dry periods occur.

## Abnormalities and General Effects

Certain diseases occur in which there are extensive changes in form of growth or in the color of the tissue, such as knots, galls, etc. Some of these are produced by fungi, others by malnutrition. The effects produced by insects are described in chapter xiv. (The effects produced by malnutrition such as chlorosis and mottle-leaf are discussed by Chapman and Kelley in Vol. I, chap. vii, and by Batchelor in chap. vii, above.)

### SPHAEROPSIS KNOT

This woody enlargement is produced by the fungus *Sphaeropsis tumefaciens* Hedges. It has been reported as common on branches of limes, *Citrus aurantifolia,* in Jamaica. It has also been found less commonly in Cuba and southern Florida.

The woody, abnormal growth is at first covered with normal bark, which later becomes rough and fissured. The knots vary from 3/8 inch to 2 or 3 inches in diameter. When cut into, the surface is soft and crumbling as compared with the normal greenish bark of healthy branches. The buds on or near the knots frequently give rise to a large number of new shoots which form witches' brooms (Fawcett, 1936).

Control consists in pruning out not only the part containing diseased knots, but also enough of the branch to remove the fungus. The fungus may penetrate far beyond the original point of infection. The pruned-out parts should be burned.

[1] It was observed also in Palestine by the senior author in April, 1930.

## DECLINE AND COLLAPSE OF CITRUS TREES

Dieback of small branches and twigs, yellowing of leaves, and poor yields mark the decline of lemon and orange trees. A gradual development of this condition has been observed in trees of any age after seven to eight years. Sudden wilting and drying of the foliage, followed by death of the entire tree, is known as collapse. The affected trees look as if they were unable to get enough water despite its abundance in the soil (Sokoloff and Klotz, 1943*a*).

*Decline in general.*—Examination of the root system of trees in a state of decline or collapse reveals a dearth of healthy feeder roots and frequently many injured and dead ones. In advanced stages of decline, and in collapse, it may be difficult to find any feeder roots. Because of the similar condition of the root system, some investigators believe that the two maladies have a similar origin and that the most important feature of both is the destruction of the fibrous root system. Others believe they differ not only in degree but in origin as well.

The cause or causes of these conditions are so far uncertain. One of the primary causes of the destruction of the root system may possibly be the presence of substances, such as nitrites or hydrogen sulfide, and products of organic fermentation, such as butyric acid, which are known to be toxic to the fibrous roots. Experimentally, it has been found possible to generate nitrites by waterlogging in the presence of certain proportions of nitrates, organic matter, and soil microörganisms. Nitrites in sufficiently great concentration have been shown to kill roots directly, or in low concentrations to injure them so that they fall easy prey to the parasitic brown-rot fungi and other less aggressive organisms. It is believed that when from one cause or another the root system is unable to generate new feeders faster than the rate of destruction, the tree will deteriorate at a rate proportional to the magnitude of the difference between the two processes, if other factors are equal (Klotz and Sokoloff, 1943; Sokoloff and Klotz, 1943*a*, *b*; Klotz and Fawcett, 1944*a*; Klotz, 1944*e*, 1945*a*). No tree on any of the standard rootstocks, with the possible exception of Sampson tangelo, has shown any appreciable resistance to nitrite injury or to infection by brown-rot fungi under the conditions mentioned.

Some chemicals introduced into the soil of the root zone may, under favorable conditions, prevent the accumulation of toxic concentrations of nitrites and possibly other respiratory poisons. Investigations with such materials have not yet gone far enough to warrant any specific recommendations for avoiding decline or for restoring declining trees to health.

Encouraging results have been obtained by some growers through resorting to different orchard-management practices (Foote, 1945). To pruning and a careful regulation of the amount and frequency of irrigation, in the opinion of some observers, may be credited the recovery of declining citrus trees. It may be worth while to point out, however, that limiting irrigation to the minimum consistent with survival of the trees may prove questionable in the long run, especially on soils containing quantities of gypsum or other salts. One should endeavor, however, to prevent long periods of sogginess in the

soil. The addition of the required amount of nitrogenous fertilizers in several small, well-distributed applications should, in some orchards, be found more efficacious than application of all the chemical at one time. Some growers advise adding small quantities of fertilizer in the irrigation water near the end of the irrigation period so as to keep the chemical in the root zone. (See discussion of orange-tree quick decline, and collapse of lemon trees, pp. 585–588 below.)

Other factors that can play important parts in the complex called decline[1] are incompatibility of rootstock and top (Batchelor and Rounds, 1944), malnutrition due to deficiencies and excesses of major and minor elements and to destruction of roots and leaves, injuries caused by insects, nematodes, viruses, bacteria, and fungi, and damage done by pest-control work and adverse weather.

### CITRUS BLIGHT

This disease, also known as wilt, has been reported principally in certain parts of Florida. Investigations by Rhoads (1936) indicate that most types of the disease have their origin in unfavorable moisture conditions in the soil and are not infectious.

The first symptom is usually wilting of the foliage on trees of appreciable size, as if the tree were suffering from lack of water. It may appear more pronounced on dry hot days, but later the wilting may become chronic and continue through damp weather. A single limb near the top will frequently show signs of wilting and the condition will spread to other branches. Leaves often drop off, but sometimes the wilting is sudden and the dry leaves remain hanging. No characteristic anatomical features have been found in connection with the trouble.

The suggestions for control given by Rhoads in Florida are: (1) Restrict new plantings to more desirable types of soil. (2) Remove underlying rock or break up hardpan before planting. (3) Establish drainage of low-lying soils to avoid waterlogging in the wet season. (4) Use irrigation, if possible, as a safeguard against inadequate rainfall in droughty types of soil. (5) In the absence of irrigation, mow cover crop or use clean cultivation in the dry season. (6) Supply adequate organic matter in the soil and adequate fertilizers. (7) Retard surface drain-off on slopes by furrows on contour lines, or use other methods to conserve moisture when needed.

### BORDEAUX INJURY

In the hot, dry, interior citrus-growing areas of California, defoliation and death of small twigs follows, after a lapse of several months, the late spring and summer applications of 8-8-100 bordeaux mixture with or without 0.5

[1] Recently, a form of decline of citrus trees called "spreading decline" has been reported in Florida. Unlike the quick decline in California, it is not confined to sweet orange trees on sour stock. Grapefruit are affected most, but oranges and tangerines are also seriously injured. From any infected tree it has spread in all directions, in the last eight to ten years, at the rate of one to three trees per year. The disease is characterized by loss of leaves, lack of new growth, and later by death of many twigs and branches. Trees have not died, but have become worthless for fruit production. The cause is as yet unknown.

per cent oil emulsion. There is no spotting or burning and, although the next crop is less than normal, the trees later recover fully.

In Australia, repeated spraying of Valencia oranges with bordeaux is said to cause the production of small, coarse, pale fruit, to lessen tree vigor, and to increase the number of scale insects.

Melanose-like spots on citrus leaves have been observed in Florida following bordeaux spraying. The markings are usually larger than true melanose spots and are often irregular or stellate in form, with longitudinal splits through the pointed extensions of the spots.

Copper sprays aggravate injury from cyanide fumigation, causing fruit and leaf pitting and defoliation. Where fumigation is to follow bordeaux spray, a dilute 1-1-100 formula of the spray should be used and a period of 4 or more weeks or at least a moderate rainfall (or, for greatest safety, both) should separate the spraying and fumigation. There is some evidence that the addition of zinc sulfate ($ZnSO_4 \cdot 7H_2O$) to bordeaux mixture helps to prevent the injury. A formula of 5 pounds of zinc sulfate, 1 pound of copper sulfate, and 4 pounds of hydrated lime to 100 gallons of water is used.

Occasionally, and apparently when dull foggy weather follows the application of bordeaux to lemons, dark brown to black corrosion of the rind is produced, the extent of the necrosis being proportional to the quantity of spray deposited (Morris, Klotz, and Sokoloff, 1941). Zinc sulfate added to the dilute bordeaux mixture, making a zinc-copper-lime-water spray in a proportion of 5-1-4-100, noticeably protected the fruit from this type of injury in one large orchard experiment. Bordeaux injury became noticeably widespread in Los Angeles and Orange counties in 1944 and 1945 (Klotz and Middleton, 1945). All copper sprays were found to have been deleterious, and both fruit and leaves were injured. On the leaves, the small, round, injured areas sometimes extend through to the upper surface. There appears to be a correlation between the time of application of the sprays and the degree of severity of injury; the later in the winter season the application is made, the more severe the injury. Several apparently satisfactory substitutes for copper sprays have been found and tested in the laboratory. Field tests made thus far indicate that the two carbamates, zinc dimethyl dithiocarbamate and disodium ethylene bis-dithiocarbamate, while less protective against brown rot than copper sprays, may profitably be used in locations where injury from copper has been severe and when the grower needs to avoid copper materials prior to HCN fumigation (Klotz and Zentmyer, 1946).

Allison (1942) found that a "dark lace-like brownish black corrosion" of lemon rind was related to the presence of fresh wounds on the surface of fruit sprayed with a bordeaux mixture. The injuries may precede or follow the spray application by as long a time as 96 hours. Injury from the formation of "slush ice" is said also to assist in producing the black corrosion with bordeaux mixture. Allison recommends reducing spray-pump pressure to 350 pounds, avoiding "a narrow cutting stream of spray, keeping the nozzle at least 2 feet away from the fruit, choosing spray chemicals free from gritty material, and not spraying recently bruised fruit."

### MISCELLANEOUS LEAF, TWIG, AND BRANCH DISEASES

Spots on leaves, twigs, and branches are produced by a number of different agencies, and the primary cause is often difficult to determine if some time has elapsed since it began to operate. There are usually primary and secondary causes in which weather, nutrition, and orchard practices, as well as organisms, may play a part.

The leaf and twig spots named below, which are usually of minor importance, will not be described here. Descriptions will be found in *Citrus Diseases and Their Control* (Fawcett, 1936) at the pages here indicated: Atichia fungus, page 278; Cercospora spots, 295; Mycosphaerella leaf spots, 295; Alternaria leaf spot, 295; Pleospora leaf spot, 296; Stigmonose, 296; lightning injury, 338; witches' broom, 345; galls, 344; and mottle-leaf, 353.

## DISEASES OF TRUNK, MAIN BRANCHES, AND ROOTS

On the trunk, main branches, and roots are found some of the most destructive of the diseases. One of these, psorosis, is discussed under "Virus Diseases" (p. 567). The trunk, its main branches, and especially the roots, are the parts through which the attack is most apt to destroy the entire tree. *Prevention and successful treatment of trunk and root diseases are of the highest* importance. Where only the smaller branches, leaves, or fruit are severely damaged by diseases not systemic in nature, the diseased parts may be eliminated by pruning and a new top readily developed.

### GUM FORMATION IN GENERAL

One of the most common effects of bark diseases, especially diseases of the trunk, main branches, and upper part of the main roots, is to stimulate gum formation, and this has led to the use, by growers, of the general term "gum disease." Exuded gum is one of the most conspicuous features, and one of the first noticeable symptoms, of several bark diseases; but gum formation itself is not a serious handicap to the tree unless the bark dies or the gum plugs the wood vessels. The gum is merely a resultant, and may sometimes serve a useful purpose in flooding the tissue ahead of certain invading parasites and slowing down their progress. Frequently, gum forms near the cambium under the live bark for considerable distances, six inches to a foot or more, beyond the margin of the tissue actually invaded. The presence of exuded gum alone is not a good diagnostic character, since its appearance and form are usually much the same in a large number of different diseases and its amount depends on a number of external and internal factors such as temperature, air humidity, physiological conditions of the tissue, etc. Gum formation is not always due to the stimulus produced by invading organisms, but may result from irritations of chemical or other stimuli.[1] Where organisms are not involved, however, the gum formation is usually temporary, but may frequently be mistaken for that produced by the invasion of organisms. Some of the chemicals causing this stimulus are

[1] Recently, J. M. Wallace (unpublished MS) has shown that merely removing a few of the outermost layers of bark suffices to destroy the stimulus to gum formation.

hydrocyanic acid gas in fumigation, ant poisons on the bark, and certain toxic substances in spray materials.

### BROWN-ROT GUMMOSIS, OR FOOT ROOT

The term brown-rot gummosis is used here as proposed in the second edition of *Citrus Diseases and Their Control* (Fawcett, 1936) to include basal trunk and crown root rots of citrus caused by any species of Phytophthora. When the disease occurs at or below the surface it is often called foot rot. At least three species, *Phytophthora citrophthora, P. parasitica*, and *P. palmivora* have been known to cause very similar lesions. Furthermore, a strain of *Phytophthora cinnamomi* Rands has been found to cause a bark canker on sour orange trunks in Brazil (Fawcett and Bitancourt, 1940*b*). In Argentina, Frezzi (1940) found *P. parasitica* more frequently than *P. citrophthora* in foot-rot lesions. Placed in wounds in trunk bark, *P. syringae* Kleb produced a typical gummosis canker (Klotz, unpublished). From the nature of the lesions produced by any of the species named above, no definite distinction can be made between forms of the disease previously described as foot rot and Phythiacystis gummosis or brown-rot gummosis. The term foot rot, however, is well established in Florida for a type of this disease which attacks the crown roots of old sweet orange trees. The history of the investigations is recounted by Fawcett (1941*b*).

*Symptoms.*—On trunks or main roots of lemons or susceptible oranges, patches of bark are killed through to the wood, including the cambium. Frequently, large quantities of gum are exuded (fig. 173, *A*). Scraping the bark slightly to remove the surface layers reveals the invaded portions, darkened to a dirty, sootlike color. Only a thin layer of wood tissue is affected. The bark remains firm and intact when first killed, but shrinks and cracks longitudinally as it dries. In the lesion below the soil surface, secondary organisms usually set up fermentation and moist decay. On old orange trees and other varieties less susceptible than lemons, the progress of the disease is slower and may be arrested before the lesions become large. Large patches of bark may, however, be killed, especially at or below the soil surface, producing the type of the disease that has usually been called foot rot (fig. 187).

After the lesion of dead bark and dead cambium has attained an appreciable size, there will be found extending upward and downward from it in the region of the living cambium a zone producing a clear watery gum—the "outer gummous zone." The bark that covers it is perfectly sound in appearance, but the cambium in the affected region is yellow-ochre in color, unlike the normal color beyond the zone of influence, and the cambium in the invaded dead area is mineral brown to burnt umber. If the bark is irregular in contour, gum pockets one to two inches long are frequently formed by the accumulation of gum, and the resulting pressure tends to separate the bark from the wood. The thin layer of wood next to the dead bark of the canker is infiltrated with hardened, reddish brown gum which prevents a rapid drying and excessive cracking of the wood and discourages the entrance of wood-rotting fungi until it is dissolved away by rain.

Fig. 187. Root rot (mal di gomma) of forty-year-old seedling orange trees caused by *Phytophthora* spp.

In Florida the patches of bark that first become diseased—as pointed out by Rhoads and DeBusk (1931)—later dry and sink below the level of the healthy bark. The live bark in advance of the lesion may develop a callus formation which tends to delimit the disease, especially in an upward direction above

the soil. The old patches of bark may then crack loose and slough off. Belowground, however, the disease usually continues to spread on the main roots and laterally around the base of the trunk.

*Contributing conditions.*—Important factors in producing gummosis infection are soil and air temperatures that are favorable to it, abundant moisture in the soil in contact with susceptible bark over a sufficiently long period, and wounds or other injuries. A practice which greatly contributes to bringing on the disease is planting so deep that the susceptible bud union is at or below the ground level. The fungi readily enter through the irregularities of growth produced by adventitious buds and suckers near the bud union.

*Control.*—The most effective method of prevention is the use of resistant rootstocks, as Sampson tangelo and sour orange. The following group of citrus rootstocks are listed in increasing order of resistance to brown-rot gummosis: Rough lemon, grapefruit, sweet orange, mandarin, and sour orange. However, individuals of any of the groups may under the same conditions show resistance at variance with that indicated by the order given.

If it is necessary to use susceptible rootstocks, the trees should be planted high; it has been demonstrated that root bark is much less susceptible than stem bark. The lower part of the trunk, down to the first main lateral roots, should be exposed to the drying air by pulling the soil back from the base of the tree; and the bark of the lower twelve inches of trunk should be protected by bordeaux wash or, if fumigation is to follow, by a zinc-copper-lime wash[1] (Fawcett and Klotz, 1939*b*, 1941; Klotz and Fawcett, 1942*b*, 1944*b*; Klotz, 1944*a*, *b*, *c*, *d*).

If a depression is formed as soil is pulled back from the tree base, a circular ridge of soil may be left to exclude irrigation water. If the depression fills when rains come, the water soon percolates down and the effect is less serious than having wet soil in contact with the tree base for long periods.

When the disease breaks out, as it will in some trees on heavy soils in spite of careful attention to protective measures, the following method of treatment will be found effective for any lesion that does not affect more than half the circumference of the tree. The killed bark, which is dark brown on the inner (cambium) surface is removed with a heavy knife, the operator cutting through to the wood and removing a quarter to a half inch of healthy bark beyond the canker limits at the sides and about an inch of the uninvaded bark at the top and bottom. The apparently healthy bark of the outer gummous zone should not be disturbed; it will recover rapidly as soon as the diseased bark has been removed and the disease thus arrested. The exposed wood should be covered with bordeaux or zinc-copper-lime wash, and the entire lower trunk also should be painted over. Excised gummosis lesions above the ground level may be painted with 1 per cent potassium permanganate solution or with the washes just mentioned. As soon as the bark edges show the formation of healing callus, the wood may be covered with white lead paint, a safe carbolineum, or other dressing, to protect it against decay.

[1] Dissolve 5 parts by weight of zinc sulfate ($ZnSO_4 \cdot 7H_2O$) and 1 part of copper sulfate ($CuSO_4 \cdot 5H_2O$) in 48 parts of water and add 4 parts of hydrated lime. Stir thoroughly.

To protect young trees on susceptible rootstocks, dust the walls and bottom of the hole which is to receive the tree, and, just before planting, dust the outside of the balls with finely divided bordeaux or zinc-copper-lime (5-1-4), or immerse the balls in 2-2-100 bordeaux mixture for a brief time—not long enough to puddle the soil. Plant high so that the first lateral roots are at the general surface of the soil. Just after planting, dust the lower 8 to 12 inches of trunk and upper main lateral roots with the above-mentioned materials as dusts, or brush with the materials stirred in water to make a thin whitewash. If there has been much gummosis in the grove, this last treatment should be repeated before the second and third irrigations. Once a year, in the fall, pour a gallon of 2-2-100 bordeaux or 5-1-4-100 zinc-copper-hydrated-lime into the soil of the ball. Where conditions greatly favor infection, the protective treatments should be continued through the second year or until such time as the water from irrigation may be kept away from the trunk. Lift protectors after each irrigation to facilitate drying of soil at the base of the trunk. The trunks down to the first side roots should be inspected twice yearly during the first five years and at least once a year thereafter. Where conditions do not favor infection, as in dry climates and sandy loose soils, this maximum program may be reduced.

### DIPLODIA—PHOMOPSIS GUMMOSIS

A gummosis on lemons in Florida has been associated with a combination effect of Diplodia and Diaporthe fungi just as, in California, a severe gumming and killing of bark is sometimes associated with the same fungi in connection with shell bark (p. 558). The asexual or Phomopsis stage of *Diaporthe citri* is the one usually found. These two fungi when in association appear to induce an effect much more severe than when either is acting alone. Outer layers of bark are killed, a copious amount of gum is induced, and the inner bark is renewed over most of the area, leaving dead pockets and producing a scaling and shelling of bark, with only slow deterioration in the tree as a whole. Periods of decline and partial recovery seem to follow each other. Extremes of cold and heat, wounds, weakened growth from various causes, appear to favor this disease. When small lesions are discovered, the affected bark and wood should be removed, and the wood should be disinfected and later covered with asphalt paint or other good covering. As a rule, it is not economically profitable to treat trees when they are badly affected all over the trunks.

### DIPLODIA GUMMOSIS AND DOTHIORELLA GUMMOSIS

(See also Diplodia twig blight, p. 547, and Diplodia and Dothiorella rots, p. 515)

Two bark diseases, Diplodia gummosis, caused by *Diplodia natalensis* Evans (the imperfect stage of *Physalospora rhodina* Oke) or a similar fungus,[1] and Dothiorella gummosis, caused by the Dothiorella stage of *Botryosphaeria ribis* (Tode ex Fr.), are frequently so much alike that they cannot easily be distinguished. Both may be found on the trunk or large limbs.

[1] Other species of Diplodia, such as *D. sarmontorum* (Fries) Wollenweber (1941), are involved.

As in other forms of gummosis, one of the first visible signs is gum oozing out on the surface. In mild cases, injury may be confined to small patches of bark at certain seasons of the year. These patches often heal up and leave only a scar. In severe cases, large areas of bark are killed and the wood becomes discolored underneath. It may begin in trunks or branches weakened from cold or other causes (Klotz, 1937). Recently, this type of injury, either in conjunction or not in conjunction with shell bark, has become severe in several groves in Santa Barbara County (Calavan and White, 1947).

Diplodia, especially, may advance as a "heart rot" or "wood rot" (Fawcett, 1936; Verrall, 1942). The wood is at first merely discolored without any apparent breaking down, but later, because of the entrance of species of *Stereum, Polystictus, Schizophyllum, Fomes, Daldinia,* etc., it may become soft and punky. The small lesions that form on lemon trunks, especially when attacked by Dothiorella, are often referred to by growers as "pocket gum"; the inner bark is disintegrated and dissolved, leaving gum-filled, elongated cavities and grooves in the inner bark next to the cambium. The inner bark may be black or chocolate brown in color. The same general treatment as for Botrytis gummosis may be used for the "pocket gum" type of the disease.

### BOTRYTIS GUMMOSIS

(See also Botrytis twig blight, p. 548, and Botrytis rot, p. 512)

This type of bark disease, produced by *Botrytis cinerea* Pers., has been reported principally in California, but the fungus causing it is probably of world-wide distribution. Botrytis gummosis is usually a disease of minor importance.

*Symptoms.*—In the active stage there is a softening of the invaded tissue, and under damp cool conditions there develops on the surface a gray-colored furry mat produced by the fruiting bodies of the fungus. Later there will be found a central spot where the bark is killed through to the wood. The gummosis sometimes accompanies decorticosis or shell bark, in which the outer bark on lemon trees cracks and breaks away in longitudinal strips.

Since the disease appears to depend principally on abrasions, cracks, or other injuries to the bark, special care is necessary, particularly in moist weather, to avoid injuries to the bark during various orchard operations. The danger may be lessened by painting the tree trunk with bordeaux wash or other fungicides or spraying the trunks thoroughly with bordeaux mixture. Frost damage or other factors weakening the bark may open a way for the fungus.

The invaded tissues should be scraped or cut away and the outer layers of bark for some distance beyond the lesions should be scraped, as in the treatment of shell bark.

### SHELL BARK, OR DECORTICOSIS

Shell bark, or decorticosis, which affects mainly the bark of lemon trunks, occurs in nearly all regions of the world where lemons of Mediterranean origin are grown.

The outer bark dies, dries, shrinks, cracks, and in advanced stages tends partly to loosen in vertical strips, leaving the inner bark and cambium alive. The disease most often starts at the bud union and extends upward, and usually affects the largest limbs on only very old trees. Young bark appears to be immune. In severe cases in which fungi such as *Diaporthe citri, Diplodia natalensis,* or others accompany the disorder, the foliage becomes sparse, leaves partly lose their green color and fall prematurely, leaving some bare twigs. In milder cases, as on Lisbon lemons, shell bark progresses very slowly and may never show any striking damage, because the bark underneath recovers almost as rapidly as the disease develops.

Recent investigations by Calavan (1947) have shown that, in the middle layers of the bark, lesions occur, prior to shell-bark lesions, that are free from fungi and are not a direct result of fungus attack. Later, as the lesions enlarge and extend to the surface, they become invaded by various fungi: *Diaporthe citri, Diplodia* spp., *Botryosphaeria ribis, Alternaria citri, Fusarium* spp., *Colletotrichum gloeosporioides,* and others. It is not yet clear what part these fungi play in severe cases of shell bark, but none of them appears to be the primary cause of shell bark.

Calavan (1947) has also found a definite direct relationship between the thickness of the bark and the tendency to shell-bark development. The Lisbon lemon, which is less susceptible, has thinner bark than the Eureka, which is notably susceptible.

Shell bark may be avoided by the selection, for new plantings, of strains derived from bud-parent trees that have shown possibilities of resistance to the disease. This should at least reduce greatly the premature appearance of shell bark. It will also probably reduce the rapidity of development of shell bark and thus diminish the injury to the trees.

### DRY BARK (SICCORTOSIS) OF LEMON

In coastal groves, the bark of the trunk and larger branches of many lemon trees have been found affected by what may be a particularly virulent form of shell bark. Both the Eureka and the Lisbon varieties on all commercial rootstocks are affected. The usual age range of the Eureka variety when it is attacked is six to fifteen years; that of the Lisbon, several years older. The bark is rapidly killed from two-thirds through the cambium to entirely through it, in large or small areas. Lesions usually appear first near the bud union or crotches of large limbs. As with any form of girdling or partial girdling, yellowing of leaves and defoliation follows destruction of the bark. In advanced stages following defoliation, the small roots starve and deteriorate. The decayed bark is gray to tan in color. A hard gum may or may not be present in inner bark, cambium, and on the outside surface of the bark. Vertical and horizontal cracks develop in the affected bark as it dries. The texture of the dead bark is punky. Several fungi, including *Diaporthe citri, Botryosphaeria ribis, Botrytis cinerea,* and *Diplodia* sp., have been isolated from the affected bark. Each is capable of killing bark when inoculated into a wound. However, the fact that these fungi seldom cause serious damage to trees that

have not previously been injured by such agencies as sunburn, cold, and chemicals suggests the possibility that some unknown agency starts the initial lesion and makes the bark amenable to invasion by these fungi. If the trunk is not more than half girdled, the affected bark and the wood, where invaded by *Diplodia* or *Botryosphaeria,* should be cut away and the wound covered with a safe carbolineum. If a new orchard is being started, budwood should be taken from coastal orchards of the Eureka variety which are twenty years old or more and which show no evidence of shell bark or dry bark; for the Lisbon variety, the budwood should be taken from healthy trees of coastal orchards at least thirty years old.

### EXOCORTIS

A shelling or scaling of bark on trifoliate orange (*Poncirus trifoliata*) trunks is here named exocortis.[1] It appears to be different from shell bark (p. 558), which it most closely resembles. It consists of narrow, vertical, thin strips of partly loosened outer bark, about 1/4 to 1/2 inch wide and 1/16 to 1/8 inch thick. Orange and grapefruit trees on trifoliate stocks so affected are much stunted, while trees on healthy trifoliate stocks grow well in the same orchards. It is suspected that it is caused by a virus, but this has not been experimentally verified as yet.

### BARK ROT OF SOUR ORANGE ROOTSTOCK

A disease of the bark of sour orange rootstocks of Valencia orange trees has recently been found in Ventura County, California (Cålavan and Klotz, unpublished). The area affected is the sour orange bark only, and may extend from the bud union to a foot or more below ground level. The injury may involve only the outer half or two-thirds of the bark thickness, but sometimes it extends through to the wood, causing a vitreous gummy or resinous infiltrated degeneration that may or may not be accompanied by gum on the bark surface. Where the disease does not kill through to the cambium, there is some regeneration of islands of new bark. The dead bark above the soil surface eventually cracks and sloughs off. Accompanying the type of injury described, there is frequently a dry type of bark rot which involves the entire thickness of the bark. Several fungi, *Fusarium* spp., *Ascochyta* sp., and *Colletotrichum* sp., have been isolated from the lesions but have failed to reproduce the disease. Transmission by bark patch grafts from diseased to healthy rootstocks is being attempted.

### RIO GRANDE WOOD NECROSIS

A wood necrosis accompanied by gum formation has been briefly described by G. H. Godfrey (1945). It occurs in the lower Rio Grande Valley on sweet orange, grapefruit, and Meyer lemon. Sour orange stock appears to be immune. It is stated that gum arises from cracks in the bark that connect with irregular bands of necrotic wood.

It is believed by Godfrey to be caused by an infectious organism that gains entrance at unprotected pruning wounds, in branches broken by storms, in

[1] *Exo-*, outside; *cortis* from *corti(ci)s,* pertaining to bark.

cracks occurring after freezes, and in injuries from chance blows by orchard workers' shoes at picking and pruning time. The necrotic regions of wood often lie an inch or more beneath the surface. They are irregular in size, varying from ¼ inch to 2 inches in thickness, and may be several inches wide. The spread from a point of origin is greater upward and downward than laterally. Affected wood is firm and slightly darker than normal wood except at the advancing border, which is salmon pink. In the pink border, hyphae and spores of very small diameter, suggesting an actinomycete, have been observed in microscopic sections by Godfrey. Attempts made to culture this organism have failed. Inoculation of healthy wood by means of small bits of wood from the pink border have transmitted the necrotic bands. The deadwood in older necrotic regions was found to be invaded by secondary organisms, chiefly *Diplodia natalensis.*

### ARMILLARIA ROOT ROT

Armillaria root rot, also called fungus root rot and oak-root fungus, caused by the toadstool fungus, *Armillaria mellea* (Vahl) Quel., is serious in certain local areas in California. It is similar to the Clitocybe root rot found in Florida.

*Symptoms.*—The aboveground evidence of this disease is either a sudden wilting or a more gradual deterioration showing as yellowing and dropping of the foliage in a part of the tree or over the entire tree. The definite evidence is below the ground surface, on the roots. It begins as a puffing or swelling of the bark. Later the fungus shows as: (1) white, felty, fan-shaped growth under and in the bark; (2) cordlike, purplish brown rhizomorphs on the root surface; and (3) occasionally, but not generally, light brown toadstools aboveground. The fan-shaped white to light pinkish mycelium that shows as the bark is pulled away is one of the best diagnostic characters. The cordlike, brown to black rhizomorphs, which resemble small roots on the bark surface, are also a good identifying symptom when present. Each rhizomorph consists of a bundle of fungus threads, the outer layer of which has hardened into a shell. The toadstools, usually in clusters, are light tan with tiny brown scales on top of the cap. The lower surface is white or dull white with white spores. A delicate ring usually occurs on the stalk below the opened cap. The toadstools (fig. 188) ordinarily are present only during late autumn or early winter. They last only a short time before becoming infested with insect larvae and disintegrating.

*Contributing conditions.*—The disease is most apt to occur where susceptible native or introduced trees infected with this fungus have been taken out and citrus trees have been planted in their places. As the roots of the citrus trees come in contact with pieces of the old native tree roots that are infected with Armillaria, the fungus attacks them. In California, the native oaks and sycamores, and susceptible deciduous trees such as apricot and peach and the introduced pepper tree, *Schinus molle* Linn., are the trees which seem most often to transmit the malady to citrus. Since the disease is favored by damp conditions, and cannot spread rapidly under dry ones, the exposure of an actively spreading lesion on a large root to the drying effect of the air will

Fig. 188. Armillaria root rot caused by *A. mellea*: (*top*) sporophores in several stages of development; (*middle*) sporophores and shoestrings or rhizomorphs on sweet orange root; (*lower left*) sporophores and affected roots and trunk of *Prunus* sp.; (*lower right*) sporophores near affected Valencia tree.

usually halt the advance of the fungus. The fungus often occurs in localized areas in an orchard.

*Control measures.*—Preliminary to control, the outlines of the area should be definitely located by digging around the crown roots, trenching, and thoroughly examining the roots. The two major problems in control are: (1) elimination of the fungus, together with the trees, from an infected area, and (2) prevention of spread of the disease to healthy areas while the infected trees still remain. In pulling or digging infected trees, remove as many of the medium and large roots as possible. Then, after the soil is allowed to dry well to a depth that includes the root zone, use carbon bisulfide, 2 ounces per hole, in holes 8 to 12 inches deep and 18 inches apart in rows also 18 inches apart, the holes in each row being staggered with those in the next. Four extra holes about 5 feet deep should be made near the former location of tree trunks where deep roots occur. The topsoil should be wet to a depth of 2 or 3 inches just before the holes are made, so that it may act as a blanket over the drier soil below, in which the gas from the carbon bisulfide is to act. The holes should be plugged with soil immediately after the liquid is applied.

If infected trees are to be left standing, with or without treatment, make a single row of holes, 18 inches apart and 8 to 12 inches deep, in the bottom of a trench surrounding the diseased area, and inject carbon bisulfide as described above. Next, in the soil of the refilled trench make another row of holes and again inject carbon bisulfide. The latter row of holes should extend outside of the infected area, isolating it from the healthy areas. This barrier treatment should be renewed every six months as long as infected trees remain. The life of trees only lightly affected may be prolonged if affected spots on large roots at the base of the trunk are exposed to air, visibly diseased tissue is cut away, and the parts of roots on which lesions have occurred are thoroughly dried out in summer. See Fawcett (1936) and Bliss[1] for further details.

## CLITOCYBE ROOT ROT

Clitocybe root rot, caused by *Clitocybe tabescens* (Scop.) Bres., is similar to Armillaria root rot in general appearance and requires a similar treatment (Rhoads and DeBusk, 1931). Its known occurrence on citrus is limited to Florida. It attacks other fruit and forest trees in the southern states from Florida to North Carolina and to Missouri, Oklahoma, and Texas. On citrus it is found mostly on Rough lemon and sweet orange rootstock, but not on sour orange. One of the most commonly attacked trees in Florida is the Australian pine, *Casuarina equisetifolia*.

In the absence of toadstools no easy way is known of distinguishing between Clitocybe root rot and Armillaria root rot. The two rots show the same type of fan-shaped mycelial growth between bark and wood, and black strands of fungus imbedded in the outer bark. One distinction is the absence, in Clitocybe root rot, of the brown to black superficial rhizomorphs growing over the surface of the bark; but since these are not always present in Armillaria root rot,

[1] See *Suggestions for the Control of Armillaria Root Rot in Citrus*, University of California Circular (lithographed), 1944.

their absence alone is not a sure diagnostic character. The stem of the Clitocybe toadstool always lacks the annulus or collar which is usually found on the stalk of the Armillaria toadstool.

### DRY ROOT ROT

This term has been used rather loosely for certain root rots the causes of which are not known, and probably covers some of what is now loosely called "decline disease" in California. The word "dry" applies to this root rot only in its later stages. In the early active stage of the disease the bark may be moist; if the soil is wet it may even be semimushy. Not all the factors of cause and occurrence are yet known. It is thought to be related to unfavorable moisture or air conditions in the soil. It has been confused with cyanide injury, kerosene-spray injury, old attacks of foot rot caused by Phytophthora, old gopher injuries, and other causes. Dry root rot as known in California is not a clear-cut disease. One or more species of *Fusarium* are almost always found associated with it, but inoculation experiments with these have so far failed to reproduce the disease in its severe typical form. At most, the *Fusarium* inoculations have caused only very small and insignificant lesions, and these fungi are thought to be secondary. Sometimes almost all of the main roots and rootlets may be affected in varying degrees. The rot may start on one side of the taproot or on the larger lateral roots and spread around them; the lesions may be old ones caused by Phytophthora or other agencies. Hard deadwood is found underneath and there is usually a tendency for lesions to enlarge for a time and then to become self-limited. Small lesions may sometimes be covered over by new bark.

The manifestations of disease aboveground are, first, an open, thin appearance of the tree, followed by yellowing and dropping of foliage and frequently by the setting of an unusually large crop. The foliage may wilt suddenly and the twigs dry up in a few days, as in the collapse stage of orange-tree quick decline (see p. 585).

No satisfactory method of control appears feasible for advanced stages of the disease, since the wood as well as the bark is badly affected. In milder cases, when only some of the roots are affected, these may be cut out and destroyed, and if the lesions are not too far advanced on the large crown roots the diseased bark and wood may be cut away to a distance beyond the visible margin and disinfected with mercuric cyanide or mercuric chloride (1 to 500) and allowed to dry thoroughly. Before the soil is replaced, the cuts may be covered with thick asphalt paint or tar. A measure helpful to prevention is not to permit an excess of water near the crown roots.

### ROSELLINIA ROOT DISEASE

This root rot, caused by the fungi *Rosellinia pepo* Pat. and *R. bunodes* (B. and Br.) Sacc., has been found in the tropics, especially in proximity to dead and dying stumps on forest lands in the West Indies. It attacks other plants besides citrus. In some of its manifestations it is not unlike the Armillaria root rot.

*Symptoms.*—Trees recently killed show most of the lateral roots dead, with their surfaces covered with mats of fungus, dark brown and intermixed with earth. Underneath the bark on the wood are fan-shaped mycelial masses that turn yellow when old. There may be a thin, black, carbonaceous growth on the surface of old roots at the base of the trunk. A dark olive-green continuous weft of fungus may extend a foot or more below the soil.

*Control.*—Removal of all stumps and logs from newly cleared land before planting lime trees is advised by Nowell (1923) as an ideal means of prevention. If this is not economically possible, trees may be planted in blocks or squares isolated one from another by means of trench drains. Since the fungi causing the disease thrive especially in continuously damp situations and cannot persist under dry conditions, free circulation of air under the trees should be obtained by cutting off low hanging branches and clearing away the weeds. Light cases may be successfully treated, thus preventing them from becoming new centers of distribution. To prevent the spread of the fungus a checkerboard of trenches may be used, isolating each tree from its neighbor, in addition to the main isolation trench around the old, suspected area.

### COTTON ROOT ROT

This minor disease of citrus, found in Texas and occasionally in Arizona, is caused by the fungus *Phymatotrichum omnivorum* (Shear) Duggar.

The aboveground symptoms first show as a yellowing of foliage and an undue shedding of leaves. Later the leaves suddenly wilt, and the tree dies within a few days, the dried leaves still hanging on its branches.

The belowground symptoms are (1) strands of parallel and anastomosing fungus hyphae which at first are white, later becoming yellowish buff, and which grow on the roots and into the contiguous soil; (2) small, dark, firm, rounded bodies, usually smaller than radish seed, produced in the soil near infected roots; and (3) a spore mat, the Phymatotrichum stage, at first a whitish, flat, fluffy growth on the soil surface, later becoming a cushionlike mass, on the exposed part of which are produced minute buff-colored spores. As a treatment in Texas, Bach suggests making holes 1¼ inches in diameter in the soil, starting 4 to 6 inches from the trunk at the bottom of a basin and extending 12 to 18 inches into the soil, in a sloping direction toward the taproot. Ten gallons of water in which 1 pound of copper sulfate has been dissolved is poured into the basin in one or several applications. In correspondence, R. B. Streets of the Arizona Station reports beneficial effects on infected deciduous trees by soil treatment with ammonium sulfate. He scattered 10 pounds of the fertilizer over each 100 square feet of soil and flooded with 2½ inches of water.

### HARD ROOT ROT

This disease occurs in Southern Rhodesia, where it is attributed to the presence of *Rhizoctonia lamellifera* Small acting under adverse conditions for the host.

The bark cracks just above the bud union, occasionally extending up the trunk without gum except in rare cases. As the bark sloughs off, the wood is

seen to be light buff. The affected roots become dry, brittle, and light in color, and the bark becomes a loose, fragile, enclosing cylinder. The inner layer of the bark of roots is usually jet black, sometimes adhering as a black incrustation. The wood may be pinkish brown, with numerous small black bodies measuring at most $\frac{1}{32}$ inch in diameter.

Hopkins (1929) reports that, in Southern Rhodesia, inarching, together with cutting away and destroying large diseased lateral roots, offers possibilities of successful treatment. All diseased wood should be cut away, and wounds should be disinfected with mercuric chloride (1 part to 1,000 parts of water) and then covered with asphalt paint or other covering. In the planting of new trees care should be taken not to produce unnecessary wounds or to use excessive water for too long a time at the base.

### CITRUS NEMATODE INJURY

The small feeder roots of citrus are attacked by microscopic worms belonging to the group called nemas or nematodes. The one most abundant on citrus is *Tylenchulus semipenetrans* Cobb., the citrus nematode which has been found generally in citrus orchards in southern California and in a number of other regions (Thomas, 1923). It has been reported by Carvalho (1942) as causing injury to citrus trees in the Central District of the State of São Paulo, Brazil. Other nematodes that have been found to infect roots of citrus in California are the meadow nematode, *Pratylenchus pratensis* (de Man) Filipjev,[1] and the banana nematode, *P. musicola* (Cobb) Filipjev.

On roots infested with *Tylenchulus semipenetrans* the soil particles cling rather tenaciously, owing to the secretion by the worms of a gelatinous material in which their eggs are embedded. When the root is heavily infested, the bark usually separates readily from the woody central cylinder. That nematodes play a part in the destruction of feeder roots must be assumed, although the relative importance of this factor in the orchard has not been thoroughly established. The work of Thomas (1923) shows definitely that heavily infested trees in large plots slowly deteriorate, as compared with uninfested trees.

Observations indicate that unknown factors cause great fluctuations in nematode populations on the roots of citrus trees. At some times, enormous numbers will be found attacking the roots; at others, indeed throughout entire seasons, very few. An excessive multiplication of nematodes, with their probably bad effects on the tree, followed by periods of apparent diminution and with partial recovery of the tree, is attributed to unknown factors influencing and controlling the number of nematodes.

Linford *et al.* (1938) found that the population of the common garden nematode, a different species, was greatly diminished by the addition of certain forms of organic matter to the soil. They list fifty-two enemies of this species, many of them fungi.

Satisfactory means of preventing an excessive increase of citrus nematodes

[1] Identified by Gerald Thorne, Bureau of Plant Industry; letter to H. S. Fawcett, January 9, 1943.

on roots have not yet been devised. On many good soils, good orchard practices, with abundant fertilization, have maintained profitable trees during most years, even though there were sizable numbers of nematodes on the roots.

### MISCELLANEOUS FORMS OF INJURY TO TRUNK, MAIN BRANCHES, AND ROOTS

For want of space, the injuries named below will not be described here. Descriptions of them may be found in *Citrus Diseases and Their Control* (Fawcett, 1936) at the page or pages designated: Sclerotinia gummosis, page 134; fumigation injury, pages 184–187; rodent injury, 184; gas and oil injury, 153; Torula fungus, 218; bark spot of Brazil, 219; fire ant injury, 219; red root rot, 142; Macrophomina root rot, 140; Ganoderma root rot, 142; Rhizoctonia rot and damp off, 96, 142; and water injury associated with species of Phoma, Ustulina, Poria, Fomes, Fusarium, 146–150; and mycorhizal fungus,[1] page 155.

## VIRUS OR VIRUS-LIKE DISEASES

A number of maladies showing the symptoms that are characteristic of virus diseases, or similar symptoms, will be included here. That some of these are virus diseases is only suspected. That they are transmitted by a virus has been proved only for those so described. Until it is known positively that the others are virus diseases, no Latin binomial names of viruses should be applied to them (Fawcett, 1940, 1942). On further study, some of them may prove to be merely different manifestations or varieties produced by the same causal agent. Some that show symptoms resembling those of virus diseases may prove to result from other causes than virus. Some of the symptoms may be attributable to inherent bud variation or to mixtures of virus infection and bud variation. However, they are included here until their real nature is known.

### PSOROSIS

Psorosis, also called "scaly bark" in California, is world-wide in distribution and should not be confused with leprosis (see p. 578), called "scaly bark" in Florida, where psorosis also occurs. Psorosis manifests itself on leaves as well as on the bark. It is caused by a virus (Fawcett, 1933*a*), *Citrivir psorosis* (Fawcett, 1940, 1941*a*). The term psorosis has recently been expanded to include certain manifestations of disease which previously were thought to be separate diseases but which now are attributed to the activity of varieties of the psorosis virus (Fawcett and Klotz, 1938; Fawcett and Bitancourt, 1943): psorosis A, attributed to the virus *Citrivir psorosis* var. *vulgare* Faw.; psorosis B, to *C. psorosis* var. *anulatum* Faw.; concave gum psorosis, to *C. psorosis* var. *concavum* Faw.; and blind-pocket psorosis, to *C. psorosis* var. *alveolatum* Faw. For crinkly-leaf psorosis and infectious-variegation psorosis, both of which are diseases attacking lemons, one of the varieties or a mixture of them may be held accountable. All these varieties have been transmitted by uniting living tissue of diseased trees with healthy tissue of psorosis-free trees, but in no other manner (Fawcett, 1936, 1939*a*, *b*, 1941*a*, *b*; Rhoads, 1942).

[1] See also Neill (1944).

*Symptoms on young leaves.*—Many small, elongated, light-colored areas occur in the region of the small veinlets. On young tender leaves not only the veinlets themselves, but also the adjacent tissue, may show faint to pronounced clearing. These small, cleared places, about 1 to 3 millimeters long and 1/4 mm. to 1 mm. broad, may be numerous and scattered over the entire blade, or may occupy only certain parts of it. Sometimes only a small proportion


Fig. 189. Young leaf symptoms similar in all varieties of psorosis: *A*, *B*, diseased; *C*, healthy.

of the young leaves show these symptoms, but at others a majority will show them. Often the pattern is not distinct; spots fade out gradually at the margins, or run together. Frequently, a distinct pattern is formed by the cleared regions, making what is known as an "oak-leaf pattern" (fig. 189, *A*). Veinlet clearing alone is sometimes seen. To see these symptoms most readily, the young fourth- to half-grown leaves, while shaded, should be viewed with the light of the sky coming through them. The lighter green areas will show in contrast to the darker green of the rest of the blade. Such symptoms are common to trees affected with different strains or varieties of what is considered to be the same virus.

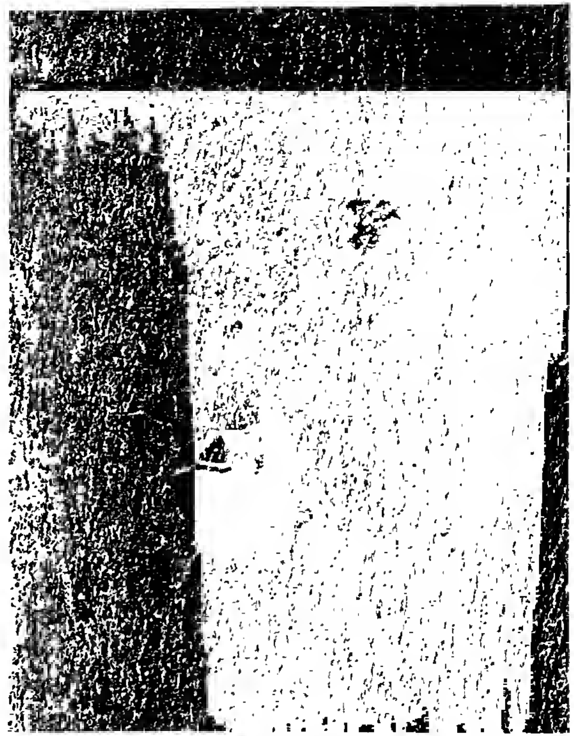
Great caution is necessary to prevent mistaking, for psorosis, injuries caused by thrips, red spider, small hailstones, or minute sand grains driven by wind, all of which may produce similar-sized markings. Frequently, other symptoms occur on mature leaves, especially in psorosis B (see p. 571).

*Psorosis A.*—This is by far the most common variety of psorosis. It is caused by the virus *Citrivir psorosis* var. *vulgare* (Fawcett, 1941*a*). Although slower to develop deleterious effects, and less serious in its effects on a given tree, psorosis A does much more damage than psorosis B. The citrus species most severely affected by psorosis A, so far as bark lesions are concerned, are sweet orange, grapefruit, and tangerines, but other species show leaf symptoms and deterioration when subjected to virulent strains of the virus. The disease usually begins on the bark, either as scales of bark with or without gum formation, or as aggregations of small pustules under which are brown specks (fig. 190, *B*). The scales of outer bark are dry, irregular flakes, $\frac{1}{12}$ to $\frac{1}{8}$ inch in thickness (fig. 190, *A*), with live, tan- to buff-colored bark underneath. This form usually first occurs in localized areas on some of the older bark of trunk or limbs of trees from six to twelve or more years of age. As the scaling advances, the deeper layers of bark and even the wood become visibly affected. Gum often forms, in small or large amounts, varying with weather and growth conditions. The rate of scaling varies on different trees. After the lesion has been present for some years, gummy deposits occur beneath and between layers of wood corresponding to years or seasons of growth. Later the wood becomes drab to brown or reddish brown in color, the discoloration progressing in an irregular fashion, not necessarily following the grain of the wood. The tree then deteriorates rapidly; leaves that form are small, yellow, and few in number (Bitancourt, Fawcett, and Wallace, 1943).

Prevention of psorosis A, as well as other associated forms of virus disease, consists in planting trees originating only from bud-parent trees that are free from these virus forms. Trees originating from psorosis-free bud parents registered by the State Department of Agriculture are now available in many California citrus nurseries (Fawcett, 1936, 1939*b*, 1944).

Treatment of psorosis A to prolong the usefulness of the affected tree consists in scraping the bark or painting with dinitro as suggested below before the tree shows any visible deterioration in foliage. No permanent cure is known. After wood discoloration sets in and noticeable deterioration of foliage and twigs is seen, it is not as a rule economically profitable to attempt treatment. When lesions are small, not larger than one's hand, scrape deep enough or paint with dinitro (see below) to eliminate discolored layers. Scrape the outer layers of the not visibly affected surrounding bark for a distance of 6 to 8 inches above and below and 4 to 6 inches on each side, or apply dinitro without scraping. Except in very wet weather, no disinfectant after scraping need be used. If an affected area covers more than one-third the circumference of the trunk it is not possible to scrape deeply enough to eliminate all discoloration. Once deterioration of the top begins, no further treatment is usually economical. A peeling of the outer bark induced by painting the diseased and the surrounding bark 6 to 8 inches above and below and 4 to 6 inches on each side

*A*



*B*

Fig. 190. Bark symptoms of psorosis A caused by *Citrivir psorosis* var. *vulgare*.

with a 1 per cent dinitro compound in kerosene (DN 75), without scraping, is giving promising results (Fawcett and Cochran, 1944; Fawcett, 1945*a*), and is being used by many growers as a cheap substitute for scraping.

*Psorosis B.*—The virus of psorosis B is called *Citrivir psorosis* var. *anulatum* (Fawcett, 1940, 1941*a*). Psorosis B is the less frequent variety and differs from psorosis A in showing gum formation in advance of, rather than after, scaling. It also shows a rapid advance of scaling in a continuous strip or area, usually along one side of the trunk or main branch and even into much smaller limbs and twigs than is usual for psorosis B (fig. 191).

The symptoms on young leaves are the same as in psorosis A. Mature leaves and fruit on trees with psorosis B may have circular spots or ring spots noticeably different from the minute flecks seen on young leaves. These spots frequently consist of concentric rings, some parts of which on navel orange fruit may become necrotic and sunken (fig. 191). Similar spots have been seen on Valencias, lemons, and grapefruit. On the fruit, furrows and depressions making a rough, bumpy condition may result. On twigs, gumming and scaling often occur, extending to much smaller twigs than in psorosis A. Bark of water sprouts may also show ring spots similar to those on fruit and mature leaves.

Psorosis B is so rapid in its progress that no treatment is usually effective. Prevention is the same as for psorosis A.

*Concave gum psorosis.*—This form is caused by the virus *Citrivir psorosis* var. *concavum* (Fawcett, 1941*a*). Concave gum psorosis is reported in California, Brazil, and Paraguay. It has been noted most commonly on oranges. In Paraguay, Fawcett and Bitancourt (1940*a*) observed it on lemons. It has the same symptoms on young leaves as psorosis A and B and blind pocket; that is, small, clear areas or flecks in the region of the small veinlets. Most conspicuous are the broad concavities of various sizes on the trunk or limbs formed by the arrested or retarded growth of wood tissue in localized regions (fig. 174, *A*, above). These are for the most part covered with normal bark, with a crevice or crack through which, usually in summer or fall, gum may ooze to the surface. Under the bark of these concavities are masses of gummy, granulated tissue, often cinnamon to tawny or russet in color. The underlying layers of wood, which are usually thinner than normal, are impregnated with a semiliquid to cheesy or gummy substance. Few to many successive gum-filled layers of wood, alternating with layers of nearly normal wood, are found. The injurious effects may act slowly over many years, but in time numerous lesions on a tree may result in serious deterioration or even death. If there are few small concavities these may be chiseled out, but if many concavities are present no practical treatment is known. Prevention is the same as that stated for psorosis A.

*Blind-pocket psorosis.*—This variety is caused by the virus *Citrivir psorosis* var. *alveolatum* (Fawcett, 1941*a*). Blind pocket has been reported only in California, most commonly on oranges, but once on lemons. It is also associated with symptoms on young leaves similar to those shown by concave gum disease and psorosis A and B. It has two forms: the plain blind pockets in bark and

Fig. 191. Psorosis B caused by *Citrivir psorosis* var. *anulatum:* bark symptoms and ring spots on leaves and fruit.

wood (fig. 174, *B*), and the eruptive form (fig. 174, *C*). The pocket form usually differs from concave gum disease in having narrower, more abruptly depressed, troughlike regions, frequently with two almost straight, concave or convex sides which come together at an acute angle at the bottom. Some attacks show longer or shorter depressions or depressions with less abrupt slopes,

nearly resembling the concavities of concave gum disease. Under the bottom of the depressions are cores of tissue ocherous salmon in color, later impregnated with a hard, gumlike substance. Only rarely is gum forced out to the surface from these blind pockets. An eruptive lesion may occasionally occur with scaling of the bark within an area occupied by several blind pockets; it then somewhat resembles that of psorosis A, but forms thicker scales of bark and is likelier to form dead areas of bark in the lesions.

No treatment is known for either concave gum disease or blind pocket except to chisel out the concavities or pockets, if only one to a very few occur. If there are many, as in the illustrations, this is not a practicable remedy. Prevention is the same as that stated for psorosis A.

In South Africa an infectious disease called "stem pitting," which has symptoms similar to those of blind pocket, is reported on grapefruit in practically every commercial orchard in the Union.[1] A few Valencia and shaddock trees have also shown the disease. It differs from blind pocket in that very young nursery trees show symptoms.

*Crinkly-leaf psorosis.*—The virus causing crinkly leaf in lemon may be the same as some of the psorosis A strains, or it may be a mixture (Fawcett and Bitancourt, 1943). It has therefore not been given a separate name. It occurs principally as a leaf symptom of mature leaves of lemon. The young leaves show the same symptoms as for the other varieties of psorosis. Crinkly-leaf psorosis has been found principally on lemon leaves and fruit. Besides the flecking in young leaves characteristic of psorosis, the blades of mature leaves show warping and pocketing on some branches or over the entire tree. The fruit is frequently but not always coarse, rough, and misshapen on trees or branches so affected. In severe cases, fruits, especially lemons, are covered with irregular bumps. Somewhat similar temporary effects may result from improper nutrition or from the activities of mites, aphis, or other insects. Another form appears to be an inherent bud variation.

No characteristic bark symptoms occur on lemon bark, but if the tree is on a stock susceptible to bark symptoms, such as sweet orange, the characteristic bark symptoms of psorosis A will usually occur on the stock when the tree is old enough.

*Infectious-variegation psorosis.*—This form, found principally on lemon leaves (Fawcett and Klotz, 1939*a*), also shows symptoms on young leaves similar to those manifested by the other varieties as described above. Since it appears to be closely associated with crinkly leaf of lemon, presumably a form of psorosis A, the virus causing it likewise has not received a separate name. The symptoms on leaves have some resemblances to the infectious mottling (see p. 574). Infectious-variegation psorosis has been found associated with a crinkly-leaf condition of lemons (fig. 175). Portions of the leaf blade of some of the leaves lack the green color and are white to yellowish white. In some leaves the chlorotic areas are entirely on one side of the midrib, and in others they are scattered over the entire blade but not arranged in any definite

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[1] Progress report on citrus research work conducted in the Sunday's River Valley for the period 1931–1946.

pattern. Some leaves, near affected ones, appear entirely normal. The young leaves also show the flecking that is characteristic of psorosis.

Both infectious variegation and crinkly leaf have been transmitted by budding to healthy lemon, sweet orange, and sour orange trees. It is therefore useless to top-work or bud-over trees with crinkly leaf or infectious variegation, using healthy buds, since the virus will enter the new part and tend to produce the same effect in the new top.

### PETRI'S INFECTIOUS MOTTLING

A peculiar mottling of young leaves of sour orange was found by Petri in Sicily in 1930, which, because of its reported absence in lemon, appears to be different from the infectious variegation of California. Petri (1931) concluded from his experiments that the virus was probably transmitted by an aphid, *Toxoptera aurantii.* Fawcett (1941*a*) proposed the name *Citrivir italicum* for the virus. As reported by Petri, the leaves contain white, pale green, or yellow irregular areas. In some leaves, toward the apex, the discolored regions extended across the blade. Narrow green bands were left along the midrib and at the bases of the secondary veins. An increase of palisade cells caused the upper surface to protrude slightly. The affected area was a light malachite green. Leaves were also blistered and wilted. In the white parts of the leaf the cytoplasm of the palisade cells developed a gummy degeneration. Sweet orange, lemon, and mandarin leaves were not affected. Most of the affected leaves were infested with the black aphis *Toxoptera aurantii.* In some respects the symptoms reported and illustrated by Petri on sour orange leaves are similar to the infectious variegation on lemons in California. Petri reported, however, that lemons were not found to be affected in Italy. This would indicate a difference, but does not certainly prove that it is distinct. Similar leaf symptoms have been produced by budding the California form into sour orange. Prevention would consist, as for other varieties of psorosis, in the same procedure as given for psorosis A.

### TRABUT'S INFECTIOUS CHLOROSIS

In Algeria, Trabut (1913) reported what he called "chlorose infectieuse." He states that it first appeared as a clearing of the main leaf veins and later resulted in a clearing of smaller veins. This appears to differ from the infectious mottling described by Petri; but whether it may have been leaf symptoms of psorosis or general starvation it is hard to say.

### CORKY BARK

Corky bark, so termed because corklike eruptions develop in the bark (Fawcett and Bitancourt, 1943), takes on various forms which are accompanied by varied effects on the tree itself. That corky bark is a virus disease is suspected but not proved. Gumlike substances are usually mixed with the corklike cells of the lesions, and the wood underneath may also be affected. In *necrotic-cavity corky bark* the lesions are in the form of necrotic cavities, the margins of which are composed of corky, raised tissues impregnated with

hard, vitreous, gumlike material, and small scales or flakes of bark. *Crumbly-gum corky bark* occurs on orange trees in irregular, eruptive, gall-like formations and ridges, in most of which gum and broken tissue together form light brown, crumbly masses protruding from the surface. *Banded corky bark* on Valencia orange appears as raised bands of corky eruptions extending horizontally around, or part way around, the trunk or limb of the tree. These may occur as narrow horizontal bands or ridges, 1 or 2 millimeters wide and the same distance apart, over an area several inches long. In *circular-spot corky bark* the circular regions of erupted, corklike layers of bark have been found on navel orange trees and bear a remote resemblance to some types of psorosis A. In *tattoo-netted corky bark* the irregular, elongated areas, spots, and ridges of corky bark often form patterns which suggest the name "tattoo-netted." Branch growth of affected trees often shows curved twigs and shortened nodes. Badly diseased trees often have eruptive areas similar to those of psorosis A, with primary and secondary lesions in the wood or areas resembling eruptive blind pocket. Some of these may be attributable to a mixture of virus and factors of inherent bud variations.

### KNOBBY BARK

Knobby bark is a condition of trunks or limbs of orange and lemon trees which is distinguished by the presence of knobs or hard gall-like projections covered with nearly normal unbroken bark. That knobby bark is a virus disease is merely suspected, not proved. The knobs vary in size from 1 to 2 inches across and project ⅛ to ½ inch or more from the usual contour of the bark. The bark over them is of about the same thickness as in other areas. The wood tissue underneath the knobs is softer and more easily cut than normal wood, is light brownish in color, and occurs as a spheroid core extending down into, or embedded in, the normal wood. The knob shows growth in circles and curves, with a light-colored gumlike substance within.

### FLORIDA GUMMOSIS

This disease, chiefly on orange and grapefruit trees, although having much in common with psorosis A, has been distinguished from psorosis as known in Florida. That it may be caused by a virus is suspected but not proved. Longitudinal cracks first appear in the bark of trunks and larger branches, from which gum exudes and frequently runs down the bark. If not washed away by rains, the gum collects and hardens in masses. The bark on either side of the cracks becomes discolored, dies for a short distance, and separates from the wood. The areas may later heal over, scales and bits of dead bark then sloughing off, leaving a series of light-colored to brownish, resinous-appearing scars. There is often an alternation between breaking out and healing. In advanced cases, large areas of the trunk and large branches are affected, and in many ways the disease resembles advanced cases of psorosis. It is believed to be similar to, or possibly a variety of, psorosis. On theoretical grounds it is suggested that the disease may be caused by some virus producing effects similar to those of psorosis.

The bark-scraping described for psorosis is reported to be the best method of treatment for cases not too far advanced.

### BRANCH BLIGHT OF GRAPEFRUIT

A severe killing back of grapefruit branches occurs in the Imperial and Coachella valleys of California. Although it is sometimes found associated with psorosis bark lesions, it often appears independently of bark scaling and is thought to be different from psorosis. Certain branches die back from the tips in the early stages of branch blight, but as the disease progresses, lesions may extend along one side of a branch for an appreciable distance and may ultimately result in the death of the entire branch. Both bark and wood of diseased branches are killed, and during the growing season abundant gum exudes near the margins of the affected areas. Light to dark brown affected wood may extend some distance beyond the margin of dead bark. Dead bark and wood are invaded by *Torula* sp.,[1] *Diplodia* sp., and other fungi. Recent observations indicate that this disease may have a relationship to high water table, high salt content in the soil, and to sunburn on partly defoliated branches. Recent inoculations by E. C. Calavan (unpublished) have shown that the *Torula* fungus under medium to high temperatures causes lesions in live bark and wood and is probably a factor in death of tissue.

### CONVEX GUM

This disease was observed in the fall of 1941 on Kushanchow sweet orange, *Citrus sinensis,* by Lin Kung-hsiang (1943), in Fukien Province, which is in the southern part of China. The Toochow tangerine and Ponkan, both *Citrus nobilis,* were free from the disease. That it may be caused by a virus is suspected but not proved.

Bark swellings appear which produce convexities of the surface and gum formation under them; this suggested the name "convex gum." The swellings are often numerous, and generally larger on the trunk than on the twigs, the most common type averaging about 1 inch in diameter. When the swellings are cut into, brownish, semiliquid to cheesy gum is found in flattened pockets in the wood, $1/25$ to $1/5$ inch beneath the cambium. The cambium appears unaffected. When a large quantity of gum accumulates in a pocket, it breaks through and a canker-like lesion results. A less common type has swellings averaging $2/5$ inch in diameter which, when cut into, show numerous small, dark brown spots of gum in the bark.

Affected trees less than five years of age, with the common type of lesions, are killed or badly stunted; older trees may often appear uninjured.

Pending further investigation, Lin Kung-hsiang suggests the possibility that convex gum is a virus disease, possibly related to psorosis.

### CROTCH DISEASE OF TANGERINES

This disease was first noted by Fawcett and Bitancourt (1940*a*) at Asunción in 1937 (Fawcett, 1937). The same year, it was found at Salto, Uruguay, and

[1] Similar to *Torula dimidiata* found on citrus in Tulare County in 1924 (Fawcett, 1936).

at various places in Argentina (Fawcett and Bitancourt, 1940*c*). In Paraguay it was quite serious and appeared to be killing many tangerine trees and greatly injuring others. The cause is not known, but a virus is suspected. *Diplodia* sp. has also been found in some lesions and may be associated with the cause of the damage.[1]

In the crotches of the main branches are dark, water-soaked regions in which the bark is injured or killed; in advanced cases it is split open and rotted. The affected tissue ferments, giving off an alcoholic odor and producing a white foam which oozes from the splits in the bark. There appears later to be a partial healing, with formation of open cankers. In some respects but not in others these symptoms are similar to those described for bark rot of the Orient, a disease which also attacks chiefly the tangerine, or mandarin oranges. (See next section.)

A possible contributing condition may be the manner of branching observed. A great many branches were seen to form from nearly the same level on the main trunk. Their bases were crowded and formed depressed pockets where rain water accumulated and where fruits were retained and rotted.

It is possible that preventive measures would consist in pruning young trees to get a better spacing of main branches. Dead bark should be removed and the wounds treated as in brown-rot gummosis.

### BARK ROT

Bark rot is a disease, apparently confined to Oriental countries, which is widespread in China, Japan, Java, and the Philippines, especially on mandarin oranges. To a slight degree it affects calamondin (*Citrus mitis* Blanco) and papeda (*Citrus hystrix* Dc.). In some respects it resembles crotch disease of South America, described in the previous section. As has been observed of psorosis, old trees are more likely to be affected than young trees. The cause is not known, but a virus is suspected. White foam or froth, which exudes from cracks in the bark, is one of the most conspicuous symptoms. According to Lee (1923*a*), it is not a bacterial ooze, but contains masses of yeast cells and mycelia of fungi which are believed to be secondary symptoms. There is also a dissolution of the soft, actively functioning cells of the bark. Insects enter through cracks in the bark. Later the tissues are killed longitudinally and laterally and the entire affected limb is killed. The lesions occur not only on the trunk and larger limbs, but well up into the trees.

In Java the disease is reported to be prevalent only in regions where trees suffer from drought. Sufficient irrigation is suggested as a preventive measure.

### XYLOPOROSIS

This disease is prevalent mainly on sweet lime stocks in Palestine, where it was first reported by Reichert (Reichert and Perlberger, 1934). It has also been reported in Brazil by Fawcett (1937) and Fawcett and Bitancourt

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[1] The senior author isolated *Diplodia* sp. from some lesions in 1937, but does not believe that this is the causal agent. In a letter from Speroni, January 30, 1940, to H. S. Fawcett, isolation of *Diplodia* sp. is also reported.

(1937*b*), and by Moreira (1938), and has been seen in California on several stocks. That it is a virus disease is suspected but not proved.

Three stages in the development of the disease have been described in Palestine: (1) Small, roundish or ovoid depressions of various sizes occur in the wood of the stock below the bud union, and can be detected only by careful observation. They result from a deformation of the wood—small conoid pits into which corresponding pegs or protuberances of the bark fit. These effects, which may occur as early as a year after budding, are usually just below the bud union and do not extend into the scion. (2) The bark is further depressed and small depressions merge into large patches and bands. Usually, an appreciable overgrowth of the scion occurs, forming a kind of knee. The pits become numerous, giving the wood a perforated, sievelike appearance, and the stock becomes elastic and easily bent over by the weight of the top. (3) Certain parts of the bark become brown, from the inside through to the surface, begin to decay and split, and later turn blackish and peel away in pieces. The adjacent wood dries, turns dark, and decays. All leaves produced are small, and branches wither slowly until the whole top dies.

Many tests have indicated that no microörganisms are present in the first two stages of the disease, and only in the later stages after the bark is beginning to decay have fungi been found. These are apparently secondary and in no way causal.

An obvious preventive method for new plantings is to use, if possible, stocks that are immune to the disease. On trees with the susceptible sweet lime stock which has proved suitable in many soils in other respects, inarching (supplementary budding) with young resistant trees—as, for example, sour orange—planted close to the trunk has proved beneficial.

### LEPROSIS

Leprosis is also known as "nailhead rust" and "scaly bark" in Florida, and as "lepra explosiva" in Argentina. It occurs also in Brazil and Paraguay, and in the Orient. In Florida, it is severe only on sweet orange varieties and less injurious on grapefruit and sour orange. In Brazil and Argentina, leaf symptoms may occur on tangerines, lemons, limes, and citrons, as well as on sweet oranges. Bitancourt, however, reported that the Sabara variety of sweet orange, considered a hybrid, was nearly immune to the disease.

The disease develops at first as round or oval spots on twigs, leaves, and fruit (fig. 192). On twigs, the spots are at first raised above the surface and are chestnut to auburn in color; later the bark is glazed, hard, brittle, and cracked, tending finally to break into scales. When the spots increase in number, they may join, forming patches of scaly and scabby bark with an effect resembling psorosis. On the fruit in Florida, the spots, $\frac{1}{5}$ to $\frac{1}{2}$ inch in diameter, may have a chestnut brown center with a lemon yellow halo which fades imperceptibly into the normal green of immature fruit. On leaves the spots resemble those on fruit, becoming brown in color, sometimes with slightly raised concentric rings and a yellow zone in the form of a halo. Leaf spots of leprosis are rarely seen on Florida trees, but are common in Brazil, Argentina, and

Fig. 192. Leprosis or "nailhead rust" on twigs of Florida sweet orange. The disease is probably caused by a virus.

Paraguay, where great variation exists in the type and appearance of the spots. The cause is still uncertain, although it has been suspected that leprosis is a virus disease (Fawcett, 1933*b*; Bitancourt, 1935). Fungi appear not to be operative in its initial cause. West (1926), from 129 isolation tests in Florida, found only well-known organisms in about 90 per cent of the trials, and inoculations were negative. In sections cut from diseased wood he found no organisms, but only gum pockets, including only parenchyma cells between the phloem and epidermis. In Argentina, experiments indicate that it may be transferred by means of mites (Marchionatto, 1938). Bitancourt has recently made investigations of the time of maximum infection in Brazil which indicate an infectious agent. It occurs in Florida in proximity to bodies of water and also close to a species of oak, *Quercus laurifolia,* on which similar twig lesions have been found (Fawcett and Rhoads, 1939). Whether or not these factors contribute to its occurrence is not known.

Maximum treatment for Florida when trees are badly affected is as follows: (1) Spray with bordeaux-oil emulsion (6-6-100 plus 1 per cent oil) about February, before the blossoms open. (2) Follow this with thorough pruning of all dead and weakened wood. (3) Spray a second time in less than two months after the blossoms shed. (4) Spray the third time two months after the second treatment. The minimum treatment when trees are only slightly or moderately affected may be limited to the first spray, as above, or at most one spraying with pruning. In Brazil, spraying with lime-sulfur has also been found effective (Bitancourt, 1934, 1940–1941).

### CONCENTRIC RING BLOTCH

This is a spotting of unknown cause found principally on leaves. It is possibly attributable to a virus, but this has not been proved. It is widespread in South Africa, where it has been known for many years and affects most of the citrus varieties. Although it occurs principally on leaves, it is occasionally found on twigs and even on fruit.

The disease shows as minute yellow rings surrounding a dull green center. Later, two or three concentric rings may be formed. Often the upper surface of the leaf is thickly covered with spots which show through on the undersurface as indistinct yellow spots. Gum formation commonly accompanies the ring blotch. The epidermis and palisade cells are filled with a brown gummy substance which raises the cuticle to form a brown blister. When severe the disease has a tendency to cause partial or almost complete defoliation. It has certain resemblances to some spots caused by leprosis on leaves in Brazil.

### RING SPOT OF LIMES

Near Corrientes in Argentina in 1937 a leaf spot resembling a virus-caused malady was noted on West Indian limes by Fawcett and Bitancourt.[1] It is possibly a new virus disease or a manifestation of one of the psorosis varieties, but this has not been proved. Spots occupied from one-fifth to one-half the area of the leaf blade and seldom extended to the margin. The area inside

[1] From notes taken by H. S. Fawcett, April, 1937.

the spot was light green and somewhat translucent, in contrast to the normal green and opaqueness of the remaining area. The spots were formed by a series of narrow imperfect rings close together. The margin as a whole was somewhat irregular. No necrosis was observed. Red spider mites were numerous on the spots.

### ZONATE CHLOROSIS, OR CHLOROSE ZONADA

This disease occurs on leaves and fruit in Brazil. The symptoms on leaves were described by Bitancourt and Grillo (1934) as "alternating light and dark parallel zones or stripes, either forming elliptic rings or irregular lines symmetrically disposed around the midrib. The green fruits show annular or circular chlorotic areas one-fourth of an inch to an inch or more in diameter. The ripe fruits show dark brown, slightly depressed irregular areas, sometimes in the form of a ring or an arc." On such fruits there were found peculiar locations of rust mite and rust staining that seemed to correspond with the subsequent formation of dark areas of the zonate chlorosis. When severe it may greatly impair the commercial value of the fruit. The spots resemble certain mature leaf spots of psorosis B in California. Bitancourt (1935) suggested that a virus is the probable cause of this disease.

### CYCLOSIS

Cyclosis,[1] another malady suspected of being a virus disease, was first reported by J. Deslandes, and because it was found at Lavras, Minas Geraes, Brazil, it is known as the "novadoença de Lavras," Lavras disease (Fawcett *et al.*, 1936). It occurred on the leaves of the Pera and sweet seedling oranges. The symptoms are circular to elongated spots of appreciable size. Some spots are light yellow and elongated along the lateral veins, with a discolored portion on each side of the vein; others are in the form of rings. Older spots often have gum pustules along the margin or scattered over the spots. It appears to be a virus-like disease with symptoms on leaves intermediate between leprosis and zonate chlorosis.

### OMBROSIS

Ombrosis is characterized by dark maroon-colored circular spots on citron leaves found at Sorocaba, São Paulo, Brazil. It was first reported by Fawcett and Bitancourt (1937*b*). The spots have within them small dark dots probably produced by formation of hard gum. In general the spots have a slightly burned or smoked appearance. From the limited number of leaves found it is not possible to tell how serious the disease may be.

### CHRYSOSIS

Chrysosis was first found by Fawcett and Bitancourt (1937*a*, 1937*b*) in the State of Bahia, Brazil. This consisted of a yellow or golden spot resembling ring spot and suggesting a virus disease. It occurred on sour orange leaves that

[1] This disease is named cyclosis, meaning circular disease, by Fawcett and Bitancourt in an unpublished manuscript. It is also referred to by Fawcett (1937).

had numerous red spider mites on them. The mites appeared to be most numerous in the area of the spots.

### LITTLE-LEAF DISEASE OF PALESTINE

Little-leaf of Palestine, or xeromorphosis, first definitely noted in 1928, has been investigated by Reichert and Perlberger. The leaves are rather small and brittle and tend to stand upright, and young shoots often dry out at the tips. Branches have short joints, and the fruits tend to be round instead of the usual oval or elongate form of the Palestine Shamouti orange. Perlberger, when visiting California in 1946, said, on seeing the stubborn disease, that the little-leaf of Palestine and the stubborn disease in California were similar in appearance.

The disease is reported to be brought about by climatic conditions accompanying periods of high temperatures and exceptionally low humidity.

Since little-leaf is carried over into young trees budded from little-leaf trees, the use of budwood from little-leaf trees should be avoided.

### STUBBORN DISEASE

The stubborn disease has been found associated with the "acorn"[1] fruit, and the two are considered to be two symptoms of a virus disease (Fawcett, Perry, and Johnston, 1944). The virus is called *Citrivir pertinaciae* (Fawcett, 1946).

*History.*—The disease was first called the "stubborn" disease at East Highlands, California, about 1929 by J. C. Perry, who observed that, when affected navel orange trees were top-worked with healthy buds of the same variety, they were slow or "stubborn" in their growth and had the same general appearance as the original trees. The "acorn" fruit was not noted at that time. The attention of the senior author was directed to this disease in the Redlands district in 1938 by Frank R. Cole, and, about 1927, to a condition of the fruit then called "pink nose" in the Redlands district. This was later known as "acorn" fruit. In the meantime, the "acorn" fruit associated with abnormal branching was observed on navel oranges in various orchards, especially in eastern Los Angeles County and San Bernardino County by various members of the Extension Service. This type of fruit is seen only rarely on Valencia trees.

In 1941, R. G. LaRue and J. C. Johnston mapped certain navel orchards, and in one of these in the Ontario district A. R. C. Haas and L. J. Klotz made a study of the chemical and physiological characteristics of the fruit (Haas, Klotz, and Johnston, 1944*a*, 1944*b*).

The stubborn disease and the "acorn" fruit were at first thought to be entirely different troubles. It remained for J. C. Johnston to direct attention to the striking similarity of the foliage and branch characteristics. It was then observed that the "acorn" fruit, as well as the other symptoms, were to be found generally on nearly all trees so affected in the three localities in Cali-

[1] L. J. Klotz in California and J. C. Johnston in Arizona independently adopted this name for such fruit.

fornia here mentioned. Fourteen trees grown at the Citrus Experiment Station from buds from three infected trees at Redlands in 1938 showed in 1944 the leaf and branch symptoms. Half of these were top-worked with healthy buds in 1942, and the shoots from the healthy buds showed symptoms as they grew out and later produced acorn-shaped fruit (Fawcett, 1946). Pending further investigation, it may be pointed out that the disease of grapefruit in Arizona known as "crazy top," with its accompanying "acorn" fruit and blue nose, may be the same malady.

*Symptoms.*—The most constant characteristic of the disease, which is that appearing in the foliage and branches, is difficult to describe. Usually it appears most conspicuously in the winter months, when an untimely autumn growth of small branches and leaves is likely to occur on diseased navel trees. More of the leaves appear to be broader and shorter, and to bend upward more on each side of the midrib, than on healthy trees. The leaves usually tend to become somewhat chlorotic and at first more numerous in a given space, owing to greater branching of twigs, but later, in severe cases, to shed more than on healthy trees.

The growth of multiple buds and shorter internodes tends to give a somewhat brushlike appearance. Many twigs die. Trees gradually decrease in fruiting.

The fruit symptoms are more definite. The fruits are usually fewer in number, more irregular in size, and paler in color than those on healthy trees, and the proportion of "off-bloom" fruits is greater. Some of the fruits, even the fourth- to half-size green ones, may show the characteristic "acorn" shape. The acorn appearance becomes more striking in some late-season mature fruit, most of which is dropped from badly diseased trees and is almost invaribly decayed by the fungus *Colletotrichum gloeosporioides*. Mature "acorn" fruits, however, are not always found every year on diseased trees. The rind of the "acorn" fruit appears normal near the stem end and abruptly becomes thinner and smoother on the surface until it is quite thin near the stylar end. The thinning may also extend in some fruits to part or all of the stem end. In navels the stylar or navel end often takes on a pinkish cast, which suggested the name "pink nose." Frequently, especially in grapefruit, there is a blue color in the albedo of the thin portion of the rind; hence the name "blue nose" has also been used. In severe cases the pulp of the stylar end has a very sour and disagreeable taste and sometimes a disagreeable odor. Large affected trees might be mistaken for the inherent, unproductive type and for the so-called "Australian" type of navel.

*Prevention.*—Enough now appears to be known about the probable nature of this disease to suggest that care be taken to avoid budding nursery trees with buds from trees with the stubborn disease. It also suggests the usefulness of top-working affected trees with good navel buds. Whether tops of Valencia or other varieties will succeed remains to be determined. We have no definite evidence of its spread in the orchard. Observations on navels in California indicate that if it spreads other than by budding it probably does so very slowly.

## TRISTEZA DISEASE

This disease is characterized by the failure and dying of the sweet oranges, tangerines, and grapefruit on sour orange stock. It was first noted without any distinctive name in South Africa (Davis, 1924; Webber, 1925; and Marloth, 1938). Later it became serious in Java (Toxopeus, 1937) and in Argentina (Carrera, 1933; Speroni, 1936; Bitancourt, 1940), and more recently it has become so in Brazil (Bitancourt, 1940; Drummond-Gonçalves and Pereira, 1942; Pereira, 1942), where it is referred to as the "tristeza" of citrus by Moreira (1942).

*Symptoms.*—According to Carrera (1933), the first symptoms in Argentina are a gradual yellowing of leaves of the terminal shoots. The leaves later shrivel and fall. The leaf fall proceeds from above downward and from the periphery to the center. The rootlets die and new rootlets fail to form. The final result is the death of the entire tree. Speroni (1936) reports a general stunting of the tree, and a partial chlorosis and a rosette-like arrangement of the abnormally small leaves. In general, a sudden collapse, with leaves drying up on the tree, does not occur. No striking, clear-cut symptoms have yet been found that distinguish this disease from slow failure and death from various other causes. In brief, the trees stop growing; rootlets and, later, larger roots decay; leaves either turn yellow and fall or wilt and dry up suddenly in place; twigs and then branches die back; and finally the entire tree dies.

*Possible cause.*—Several theories have been proposed to account for the disease. That it is of virus origin was suggested by Fawcett and Bitancourt in a memorandum in 1937 and first published by Bitancourt (1940–1941).[1] The virus theory as interpreted and discussed in detail by Webber (1943*a*, *b*) appears to explain all the facts (see chap. ii, p. 102, and Webber's articles as cited above, for details).

Webber's theory (considering, for example, the sweet orange and sour orange combinations only) assumes that the leaves of the sour orange produce some product not produced by sweet orange leaves which inhibits the action and development of the virus and thus protects its own or other roots. When the sour orange leaves are absent, as in sweet orange scions on sour orange stock, the counteracting substance is absent and the virus becomes lethal to the sour orange roots. In the reverse combination, with sour orange leaves in the top and sweet orange roots, the roots would be protected because of the inhibiting action produced by the sour orange leaves. His theory also assumes that the leaves of successful scions like lemon on sour orange stock are either immune to the disease and thus not carriers, or that they produce an inhibitive substance that protects the sour orange roots.

Another interpretation which also fits the facts, suggested to Webber by L. C. Cochran, assumes a tissue specificity in the leaves of sweet orange for

[1] A translation from this article states (p. 65): "In conformity to the memorandum of Fawcett and Bitancourt, a virus disease latent in the sour orange and virulent to the sweet would explain the recovery of the sour orange on the suppression of the sweet orange top, but would not explain the recovery of the sweet top when inarched with resistant stocks."

the virus which develops a substance that, when translocated downward, is lethal to the sour orange stock. This would also assume that if virus invades sour orange leaves it fails to produce substances toxic to its own or other rootstocks (Rawlins and Parker, 1934). It further assumes that leaves of successful scions, like lemon on sour orange stock, would also fail to produce substances toxic to sour orange roots. A number of authors in South America have found the citrus nematodes on the roots and have postulated a direct or indirect causal relation to tristeza. This explanation does not appear plausible, because this nematode species has been known in all parts of California since 1913 without causing any disease similar to tristeza.[1]

The only practical remedy to be suggested is to inarch the trees on sour stock to other resistant stocks such as Rough lemon, sweet orange, or sweet lime, or to top-work the sweet orange trees, before they have deteriorated too far, with lemon or other resistant tops (Bitancourt, 1940–1941). For new plantings, the disease appears to be avoided by using other than sour orange stocks when sweet orange, tangerine, or grapefruit scions are involved. (For details relating to the susceptible and resistant stocks and scions, see chap. ii, pp. 100–103.)

### ORANGE-TREE QUICK DECLINE

The trouble known in California as quick decline has thus far been found attacking only sweet orange trees with sour orange rootstocks. It occurs mainly in some of the light, sandy soils of the San Gabriel Valley of Los Angeles County and its vicinity; one smaller area, in northern Orange County, has also been affected. This disease and tristeza have many effects and symptoms in common. Quick decline has recently been found experimentally to be a virus disease (Fawcett and Wallace, 1946).

A tree with quick decline behaves in some stages as if it were gophered or were attacked by oak-root fungus, girdled by footrot, badly waterlogged, or injured by nitrite, or as if it had been injured below the soil surface by kerosene or other spray. One must eliminate all these factors before saying that a suspected tree has only this form of decline.

The first symptom of quick decline to become evident in the parts aboveground is a peculiar dull color and a slight curling of leaves lengthwise and upward. Affected trees usually have an abnormally large crop, especially of inside fruit. In the fall there is noticeably less new growth, and earlier development of high fruit color as the fruit matures. By the time there is any visible evidence aboveground, starch will have disappeared from most if not all of the outer roots up to the skirts of the tree or farther inward toward the trunk (Fawcett, 1945*a*, 1945*b*).

When the trunk and main roots of trees showing severe late stages of the disease are cut longitudinally, more or less normal amounts of starch are found in the sweet trunk, but only a central cone of starch in the sour orange portion below the bud union. In trees reaching the chronic or equilibrium stage, starch reappears in roots, and new roots form for a time.

[1] Recently, transmission of tristeza by means of a species of aphis tentatively identified as the black citrus aphid, *Aphis tavaresi*, has been reported by Meneghini (1946) in Brazil.

Since healthy trees when girdled show about the same kind of progressive disappearance of starch as do trees affected by quick decline, it is indicated that the effect in the latter is a kind of girdling process. There then occurs a progressive change of foliage to distinct curling, wilting, and dropping of leaves, and later a dying back of twigs. This is accompanied by sloughing of the bark of fiber roots and progressive dying of many roots from the outer margin of the root system inward toward the trunk.

When the tops of the trees on which roots have begun to rot are cut back severely, the rot of the roots is checked, callus tends to form at the outer limits of the live bark, starch again accumulates in the previously starch-free roots, and new roots put out for a time. Such roots with starch, when detached, rot rapidly, though less so than those without starch. Affected trees, when not cut back, have not only less starch, but less sugar, and slower respiratory activity, than healthy trees. At certain seasons, some trees, especially the younger ones, suddenly collapse, and the leaves and fruit dry up in place. Many of the trees finally die. This has suggested the name "quick decline" (fig. 193). Most of the older trees, however, decline more slowly, gradually dropping their leaves until they come to a kind of equilibrium. Later they may put out considerable new growth. Some trees that were cut back and skeletonized in 1941 now (1946) have some new growth and new roots. Others have made a feeble growth of top and roots and have developed a chronic form of the trouble which may continue for several years. Still others have died. In some of those that have survived, starch reappears in the remaining live roots and in the new roots also.

A study of the bark at or near the bud union (Fawcett *et al.*, 1946) shows that diseased trees have degeneration of some to all of the sieve tubes in the bark through which the food moves to the roots. This degeneration appears to begin at or below the bud union, long before the general aboveground symptoms are apparent, and later occurs above the bud union, presumably as the result of a girdling effect. The degeneration of the sieve tubes is similar to that found in some virus diseases, such as buckskin of cherry.

### WOOD POCKET, OR LIGNO-CORTOSIS, OF LEMON

This disease has been observed only in California, and thus far only on part of the progeny from a selection of semidense Lisbon lemons. It appears to be a virus disease, and its transmission has been demonstrated.[1] The disease was first noted in 1937 in one of the experiments with Lisbon lemons on different rootstocks at the Citrus Experiment Station. It has been noted elsewhere only on Lisbon lemons propagated from the same source. The trees were ten years old when first noted. It has been referred to, but not by name, by Batchelor and Rounds (1944). Young trees propagated from buds of diseased trees showed the wood pocket after they were six years old.

The most definite symptoms appear in the wood, and this suggested the name "wood pocket," but the disease affects both wood and bark. A defect

[1] H. S. Fawcett and E. C. Calavan, "Wood pocket, a newly reported disease of lemons," *Phytopathology*. (Abstract in press.)


Fig. 193. Quick decline of sweet orange: *A*, advanced stage, showing slowly developing, chronic form; *B*, wilting and collapse, an acute form (trees ten or more years of age generally do not die, but develop the chronic form *A*; young, collapsed trees may die); *C*, roots of affected tree, showing rotting and sloughing bark; *D*, iodine test for starch in (1) root from healthy tree, showing abundance of starch (blue-black), (2) in apparently healthy root from tree with beginning stage, showing starch only in center, and (3) in apparently healthy root from affected tree showing starch entirely gone (this test is not specific for the trouble; it serves only as an aid in the identification).

or break in the bark is often the first outward symptom, but a discoloration of the wood immediately inward from the break is found. The break in the bark may be preceded in some trees by a deterioration of certain branches, or by mature leaf symptoms—described later. This first evidence may be a short, narrow, irregular vertical break in the bark of the trunk or limbs, with irregular margins of dead bark, or larger, wider, usually elongated areas. When cut into, the wood underneath is found to be discolored in an irregular pattern and filled with gum. The discoloration in longitudinal view is irregularly darkly dotted on a lighter-colored surface. Usually, it is only in older lesions that gum exudes to the bark surface. The lesions vary in size from an inch in length to large, one-sided lesions extending several feet along the larger branches. As the disease progresses, branches lose part of their leaves and die back gradually and the remaining mature leaves often become a paler green.

Another accompanying effect, not so conspicuous, is a partial loss of green color on large irregular areas of the leaf blade, often giving a variegated appearance. These areas may occupy any part of the leaf and are usually independent of the main veins. Sometimes they occupy only one area, or the lateral half, the other side being normal in color. The color in the affected areas varies from only a slight loss of green to greenish yellow to an occasional almost pure yellow. The shape of the areas is diverse in outline, and only a small proportion of the leaves on a tree exhibit them. Some areas are chimera-like in general appearance. This leaf character may be lacking or easily overlooked in many affected trees.

No suggestions for prevention of the disease can now be made, except to avoid taking propagating material from infected individuals of this strain of trees.

### COLLAPSE OF LEMON TREES

Agencies which girdle a citrus tree or directly destroy its root system can cause the sudden wilting, collapse, and death of the tree. Among them are virus infections, fungi, gophers, smudge oil, kerosene or other spray materials, other chemicals, and excess water. When thorough investigation has eliminated all other factors, one should look for the specific features that would substantiate the hypothesis of virus infection. These are chlorotic clearings in the leaves, pustules, and markings on the bark, and injury to the food-conducting system as revealed by careful sectioning with a microtome and examination with a microscope. Microscopic examination by H. Schneider of strips of bark through the bud union of several collapsed lemon trees has revealed a destruction of the food-conducting vessels, as in some other virus diseases of plants, and suggests the possibility that some cases of lemon collapse may be of virus origin.

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## Chapter XII

# BIOLOGICAL CONTROL OF INSECT PESTS

BY

HARRY S. SMITH

Biological control of insect pests may be defined as *the suppression of a pest by means of the introduction, propagation, and dissemination of the predators, the parasites, and the diseases by which it is attacked.* Probably all kinds of plant-feeding insects are attacked by diseases or enemies—usually by more than one species. Since these tend strongly to reduce the total number of the host insects reaching maturity, they are capable of playing a very important part in insect-pest control. The population density of any species is determined by the interaction of its environmental resistance and its potential reproductive capacity. Environmental resistance includes the action of all those forces which bring about premature deaths (i.e., death before the reproductive functions have been fulfilled) or which reduce fecundity. Potential reproductive capacity is a measure of the maximum capacity of the species to produce young.

Broadly speaking, it may be said that the *potential* reproductive capacity of a species is usually more or less constant. Therefore, variations in the population levels of a species are determined largely by variations in the amount of its environmental resistance. Most important among the many distinct factors of environmental resistance are food supply, meteorological conditions, host resistance, diseases, and parasitic and predatory enemies.

## THE COMPOSITION OF ENVIRONMENTAL RESISTANCE

*Food supply.*—This factor is obviously the ultimate check to increase in any pest, although it is rarely operative. Usually, other natural checks restrict the multiplication of a species before it becomes so numerous that it is limited by its food supply. Food shortage is operative only under extraordinary conditions, as when a species is introduced into an entirely new habitat where it is comparatively free from other checks; increase will then continue until starvation checks it.

*Meteorological conditions.*—No species is at all times perfectly adapted to the climatic influences which surround it. There are optimum conditions of temperature, humidity, and sunlight, departures from which in either direction tend to retard or to prevent the development of an insect. This is aside from the effects of storms, floods, freezes, and such catastrophes, which at times destroy insects in large numbers.

*Host resistance.*—Under this term are included such checks as inability of the insect to feed upon the host plant because of the physical or chemical condition of the plant. For example, the host may be too hard for young scales to penetrate with their mouthparts, or it may have some chemical characteristic which is repellent.

*Diseases.*—The population of many species of insects is materially reduced by attacks of disease. The efficacy of the discases seems for the most part to be strongly influenced by climatic conditions; but where these are favorable, as for example where high humidity is combined with warm temperatures, they are highly effective in reducing the numbers of the insect attacked. The effect of fungus or bacterial diseases in checking the increase of insect pests, and the use of such diseases as a method of pest control, are discussed in chapter xiv.

*Predatory and parasitic enemies.*—Most of these are insects, although birds, certain mammals, reptiles, and other animals are at times effectively inimical to insect pests. A parasitic insect is one that completes its development upon or within a single individual host. A predatory insect requires more than a single individual of the host or prey species for the completion of its development. There is scarcely a known insect which does not have at least one insect parasite or predator that lives at its expense, and most of those which are of economic importance have many such enemies. For example, about seventy-five different species of insect parasites are known to attack the black scale of citrus, *Saissetia oleae* (Bern.), in different parts of the world; and it also supports many species of predatory insects, particularly ladybird beetles. Some parasites and predators can, under favorable conditions, be of very great value in reducing the abundance of the species upon which they feed.

There are other limiting factors, such as cannibalism, crowding, etc., but they need not be considered here.

## THE UTILIZATION OF NATURAL CONTROL AGENCIES

If the total environmental resistance can be increased, it may reasonably be expected that the numbers of a pest will be reduced; and here lies the economic gain. It is therefore of interest to consider the possibilities of increasing the total effect of this force.

The ultimate check to increase, insufficient food supply, naturally does not lend itself to economic use. The economic aim is to increase the host plant and to prevent the insect from making use of it. Unfavorable meteorological conditions are of great importance in reducing or in maintaining low population density, but are too largely beyond the control of man to admit of practical use. Diseases can be increased in effectiveness by artificial culturing and dissemination, although their usefulness seems rather restricted because of their more direct dependence upon meteorological or climatological conditions. Parasitic and predatory insects lend themselves well to artificial handling, are relatively unaffected by meteorological variation as compared with many diseases, and practically are the most useful of the factors making up environmental resistance. Just how advantage may be taken of this force, in the biological control of insect pests of citrus, is the subject of this chapter.

Most plant-feeding insects, in their native habitat, and under conditions undisturbed by man, do not ordinarily become so abundant as to injure seriously their host plant, because usually, though not always, their parasitic and predatory enemies are effective in keeping their numbers less than would result in serious injury to the plants. When, however, these same plant-feeding

insects are introduced and established in a new habitat without being accompanied by their parasitic and predatory enemies, they often become serious pests of agriculture. Insects which have thus become pests are favorable subjects for biological control, because—as has been demonstrated on numerous occasions—to effect important reductions in the population density of the introduced plant pest it is only necessary to go to the native home of the pest, obtain the more important enemies, and establish them in the new habitat.

In undertaking work of this kind the first step is the search for the country in which the pest originated. This is often difficult, especially with respect to those insects which, like the black scale, have become almost world-wide in distribution. But sometimes the native home is already known, or may be determined by a study of what has been published about the insect. Occasionally, valuable enemies are found in regions other than the native home of the pest—parasites and predators which have taken over, as a host, an introduced insect and have become adapted to preying upon it. The finding of the country of origin of the pest is followed by study of it there, to determine what parasitic and predatory species are attacking it and to learn about their habits. This is followed by the collection and exportation of such parasites in a living condition to the country where they are to be used. (See fig. 194.)

Great care must be exercised lest dangerous insects be sent in and allowed accidentally to escape at destination. Escapes are most likely to happen when the shipments contain secondary parasites—i.e., parasites of the beneficial species—which may be so destructive as to interfere seriously with the multiplication and work of the most valuable primary parasites. For this reason, foreign material must be handled in insect-proof quarantine rooms and studied by trained men who are thoroughly qualified to distinguish between the beneficial and the injurious species. (See fig. 195.)

As soon as it is determined that a parasite or predaceous insect is possibly of value, its mass propagation is undertaken, so that it may be generally distributed in the districts infested by the host.

The successful employment of these beneficial insects is dependent upon many environmental conditions, most of which are complex and beyond the control of man. Many parasitic and predatory species apparently cannot be established successfully in certain new habitats. Many do become established but for one reason or another are not sufficiently effective to render much service. A few—and it must be acknowledged that it is only a very small proportion of the introductions—thrive and become important factors in the control of the pest they were introduced to combat.

Under certain conditions the work of insect parasites and predators can be greatly aided by mass propagation in insectaries and later distribution in the groves in large numbers; the ladybird beetle, *Cryptolaemus montrouzieri* Muls., has thus been put to work in various parts of the world. This method is not universally successful, however, because of the difficulty of rearing the beneficial species in sufficiently large numbers at a low cost, and because ordinarily if they are present at all and conditions are favorable they will exert without artificial aid the maximum effect of which they are capable.


Fig. 194. Method of transporting beneficial insects on live host plants from India to California.

Fig. 195. The insectary of the University of California Citrus Experiment Station, Riverside, California.

## THE DEVELOPMENT OF BIOLOGICAL CONTROL IN THE CITRUS INDUSTRY

Although the idea of biological control of insect pests was not originated by or within the citrus industry, it is undoubtedly a fact that the problems of that industry gave the stimulus needed to transform the idea into a potent practical weapon in the battle against the insect pests of agriculture. It was the catastrophic damage done to citrus trees by the cottony cushion scale in California that finally induced the United States government to consider the possibility that this pest might be held in subjection in its native home, Australia, by parasites and predators. An entomologist was sent to Australia to search for beneficial insects destructive to the pest, and the result, as will be related later on, was a striking success that attracted the attention of the agricultural and entomological world to the practical possibilities of this mode of attack.

In a sense, the citrus growers of California were the pioneers in this work. The successful outcome of the Vedalia introduction created an enthusiasm for biological control that has been sustained to this day, a period of more than fifty years. During all this time the State of California, first through its Department of Agriculture and now through the University of California, has striven continuously to reduce the cost of control of the insect pests of citrus by foreign exploration for enemies to use against them. As an outcome of these efforts, which are described in more detail below, results of great value have accrued to the citrus industry. Outstanding, of course, has been the almost perfect control of the cottony cushion scale and the citrophilus mealybug. Less spectacular but nevertheless of great economic value has been the control of the common mealybug and the long-tailed mealybug, and of the black scale. Much effort has been given to the search for enemies of the red scale, as will be seen in what follows, but so far with little practical success, although the Chinese race of *Comperiella bifasciata* Howard gives some grounds for belief that the situation is not entirely hopeless.

Citrus insects appear to be particularly favorable subjects for biological control, especially in the larger citrus-growing districts of the world, primarily because in these districts the major pests of citrus are not indigenous but for the most part have been introduced, and it is a well-recognized principle in biological control that introduced insects are more likely than native ones to yield to it. In most of the great citrus-growing areas of the world the genus *Citrus* itself is an introduction, and with few exceptions native insects have not been inclined to favor greatly this exotic plant group as hosts. In California only two species believed to be native, the orange tortrix, *Argyrotaenia citrana* (Fern.), and the citrus thrips, *Scirtothrips citri* (Moult.), are of major commercial importance. All other major insect pests of citrus are either definitely known or strongly believed to be introduced species. This is also true, although perhaps to a less degree, in other citrus-growing regions, and, interestingly enough, most of the major pests of citrus are the same insects throughout the world. The California red scale, *Aonidiella aurantii*

(Mask.); the Spanish red scale, *Chrysomphalus dictyospermi* (Morg.); the Florida red scale, *C. ficus* Ashmead; the purple scale, *Lepidosaphes beckii* (Newm.); the black scale, *Saissetia oleae* (Bern.); the citrus white fly, *Dialeurodes citri* (R. & H.); and several species of mealybugs, *Pseudococcus* spp., are the principal pests of citrus toward which most of the control work is directed. Though all these insects do not occur in all the citrus regions, at least several of them are found in each. There is, therefore, a community of interest among citrus entomologists everywhere, and no phase of insect control provides a better opportunity for international coöperation than the application of biological control to these insects (Smith, 1929).

Furthermore, almost all the citrus-destroying insects are scale insects, and these, as a group, lend themselves especially well to biological control, chiefly because (1) they are particularly vulnerable to attack by parasitic and predatory insects in all stages, since they are without special protection and without means of escape; (2) they are sedentary and easily visible, rendering colonization of enemies easy; and (3) parasitic and predatory insects form relatively a very important part of the composition of the environmental resistance to which they are subject, considering the group as a whole, although there are important specific exceptions. Along with these natural factors which are favorable to the application of this method is the economic one that the cost of artificial control is very high, amounting often to an annual expenditure of $50 or more per acre. This serves as a stimulus to entomologists to interest themselves in this type of control, and also tends to influence citrus growers to demand liberal support for the necessarily expensive exploration and research.

## THE BIOLOGICAL CONTROL OF IMPORTANT CITRUS PESTS*

### THE COTTONY CUSHION SCALE
*Icerya purchasi* Mask.

The cottony cushion scale, or fluted scale, first attracted attention as a pest of citrus in California. At some time between 1870 and 1875 it appeared at Menlo Park, where it attacked not only oranges and lemons, but many varieties of ornamental shrubs as well. It spread with great rapidity and soon found its way to the large commercial citrus plantings in the southern part of the State. The damage it did to this industry was very great, grove after grove being practically destroyed and others being so reduced in value that banks refused to make loans on them. Extensive research was carried out by scientists in the hope of finding a satisfactory spray or fumigant, but without much success. The insect attracted national attention and the United States Department of Agriculture stationed two investigators in California in an effort to avert what appeared might be the destruction of the citrus industry.

It was evident that the destructive scale was an immigrant from some foreign country. In addition to the work carried on in California, Riley and

* Limitations of space forbid, under this general heading, a discussion of all the insect enemies of the various pests.

Howard, Chief and Assistant Chief, respectively, of the United States Division of Entomology, undertook to determine, by correspondence and study of the records, the native habitat of the insect. As a result, it was discovered that the cottony cushion scale was a native of Australia, whence it had undoubtedly been brought to California on shipments of acacias. Correspondence with Australian entomologists further brought out the fact that the insect was rather uncommon there, rarely becoming so abundant as to cause commercial damage. The question of just what factor could account for its relative scarcity in Australia became one of great interest to the American entomologists. Inquiry regarding the insect enemies attacking the scale in Australia resulted in the sending to Washington of specimens of a tiny black fly, *Cryptochaetum iceryae* (Will.), by the Australian entomologist, Frazier S. Crawford. It was the receipt of these specimens which convinced the officials of the United States Department of Agriculture that a serious study of the scale in Australia was desirable, and which finally resulted in the sending of Albert Koebele to Australia to study the situation at first hand and to send to California such insect enemies, if he should find them, as were keeping the insect in subjection in its native home.

Koebele was evidently well qualified for the task and soon found not only the little parasitic fly previously mentioned, but also the ladybird beetle, later to become famous the world over as the Vedalia, *Rodolia cardinalis* (Muls.). This ladybird, together with the parasitic fly *Cryptochaetum* and several other species of parasitic and predaceous insects which he found to feed upon the cottony cushion scale, Koebele collected in large numbers and sent to California in a living condition. The material, when received (November, 1888), was cared for by another Federal entomologist, D. W. Coquillet, at Los Angeles. Both species arrived in excellent condition and at the proper time were released in the infested orange groves.

The outcome of these introductions was remarkable, and success greater than even the most enthusiastic supporter of the idea had hoped for was achieved. It is not an exaggeration to say that the few hundreds of ladybirds introduced into the groves probably became billions before the end of the first season, so rapidly did they multiply in the presence of an almost unlimited food supply, favorable climatic conditions, and freedom from enemies. In the face of this attack the cottony cushion scale was rapidly reduced in numbers, and within eighteen months the orange groves were again giving indications of approaching the same vigorous, healthy condition as before the advent of the scale.

The spectacular outcome of this piece of work had a striking effect among the citrus growers of California and attracted the attention of entomologists throughout the world. There was a tendency on the part of the fruitgrowers to generalize from this one example, to the effect that *all* pests could be controlled by this method, and to this degree the effect was bad, but it did stimulate the interest of entomologists in the possibilities of this type of pest control. Later, when the cottony cushion scale was discovered in Florida, Egypt, Italy, France, Portugal, South Africa, New Zealand, and the Hawaiian

Islands, it was necessary only to obtain colonies of the Vedalia from California and introduce them into the infested districts, to bring about effective control.

It will be admitted by most entomologists that this is the most nearly perfect example of biological control of an insect pest that man has thus far been able to bring about. The introduction of no other insect enemy of a pest has been so uniformly successful over so wide an area. Why is this true? Probably for the following reasons: (1) The beetle larva can reach full development within a single egg mass, thus making unnecessary a hazardous search for food by the newly hatched larva, which in most predators is a cause of greatly reduced efficiency. (2) Vedalia breeds much more rapidly than the scale, having at least two generations to the latter's one. (3) The scale and its eggs are completely exposed to attack by Vedalia. (4) The scale is fixed in location on the plant, whereas the Vedalia is extremely active. (5) Outside of its native habitat, Vedalia apparently has no important enemies of its own.

Although the cottony cushion scale occasionally becomes abundant on single trees or in very restricted localities, it is usually necessary to wait only a short time before the Vedalia puts in its appearance and cleans up the infestation. Sometimes, though not often, it is desirable to recolonize the Vedalia in localities from which it has temporarily disappeared. The beetles may usually be obtained through some of the governmental institutions serving agriculture.

The spraying of infested citrus trees with arsenical sprays, a practice which prevailed at one time, was often disastrous because the egg sacs of the scale absorb the poison and this is fatal to the Vedalia. Thus the scale, if it is protected from the attack of its principal insect enemy, will again approach the capabilities of destruction which it exhibited in the early days before the introduction of Vedalia. This has actually occurred in several localities, and some of the trees did not entirely recover from the attack of the scale for several years. Recently, with the advent of new insecticides, it appears that there is some danger of this kind from the use of sprays other than arsenic. DDT, for example, is very destructive to the adult Vedalia and under certain conditions its use is accompanied by a considerable build-up of the cottony cushion scale.

The great development of potent new insecticides now taking place may create difficult problems for the economic entomologist through destruction of beneficial insects which are valuable in the control of pests other than the one against which the treatment is directed. How far this problem will develop is not yet fully evident.

The adult Vedalia beetles are brilliant red heavily marked with black, and are about 2.5 to 3.5 millimeters in length. The eggs are laid usually within the egg sac of the scale, and the larvae tend to remain hidden in the sac while going through their early development. They are pinkish in color, with dark markings as they grow older. They pupate on the leaves or bark of the host plant to which they attach themselves.

Besides the Vedalia, the little black parasitic fly, *Cryptochaetum iceryae* (Will.), also introduced from Australia, is of great importance in the control of cottony cushion scale. It does not seem to be quite so effective on mature

citrus trees as on young trees and shrubs, and in California it apparently is better adapted to coastal than to interior conditions, although it occurs commonly under both. Under some conditions it has actually proved more effective than the Vedalia, though this is not generally true (Smith and Compere, 1916; Thorpe, 1931).

### THE BLACK SCALE

*Saissetia oleae* (Bern.)

The cost of controlling the black scale, and the increasing difficulty of controlling it regardless of cost, have naturally resulted in stimulating interest in its insect enemies, their nature, habits, and economic importance. This pest is heavily parasitized: more than seventy-five species of primary and secondary parasites are known to attack it, in one or another part of the world, in addition to the many species of ladybird beetles and other predators of which this scale is a favorite food (Smith and Compere, 1928*c*). A great deal of effort has therefore been expended toward making practical use of this large array of insect enemies.

Perhaps the first observations of importance were those made by Comstock in California in 1880 and recorded by Howard (1881). Comstock stated that "enormous quantities of the eggs of the black scale are destroyed by the chalcid parasite, *Tomocera californica* Howard." At that time this species seemed to be the only enemy of importance attacking the black scale in California. Koebele (1893) reported that the black scale was found everywhere in New Zealand and Australia and that many species of parasites and predators were found preying upon it in those countries.

In 1895, C. P. Lounsbury, entomologist for the Union of South Africa, pointed out, in correspondence with the United States Department of Agriculture, that the black scale was rare in that country, owing to attack by several species of parasites, and that it became abundant only where the Argentine ant was present. Lounsbury's observations led to the introduction of *Scutellista cyanea* Motsch. and *Metaphycus lounsburyi* (How.) into California. (They will be described below.)

Quayle (1914) studied the black scale in the Mediterranean region and found that its most important insect enemy there was the parasite *Scutellista cyanea*. It is also attacked there by two species of ladybird beetles, *Chilocorus bipustulatus* (L.) and *Exochomus quadripustulatus* (L.). In addition to these insects, *Coccophagus lycimnia* (Walk.), *C. scutellaris* (Dalm.), and the predatory moth, *Thalpochares scitula* Rbr., are enemies of this scale in Italy. Silvestri (1915) studied the black scale in Eritrea, East Africa, and found several species of parasites attacking it in that region.

The attempt to control the black scale in California by the biological method began with the introduction of the ladybird beetle, *Rhizobius ventralis* Erich., from Australia by Koebele in 1892. The adult of this insect is about 2 to 2.5 millimeters in length, velvety black with abdomen reddish beneath. The larvae are dark gray and covered with spines and tubercles. The young larvae feed on the eggs and young beneath the parent scale and all stages feed on the scale in the open. It is now thoroughly established throughout California, but

perhaps does not exert a very great beneficial influence. Like many other scale-feeding ladybird beetles, it thrives best in heavily infested groves, and once a citrus grove is in that condition *Rhizobius* will sometimes become extremely abundant and clean it up. But no grower can afford to let his grove become heavily infested. Long before that, it is sprayed or fumigated, and under such conditions *Rhizobius* is ineffective. Although a very efficient insect under conditions of heavy infestation, it must be admitted that *Rhizobius* does not fill a very important place in the pest-control program as carried out in California at present.

In 1901 (Howard and Fiske, 1911) the parasite *Scutellista cyanea* Motsch. was introduced into California from South Africa. The introduction was accomplished through the efforts of Lounsbury, Howard, and Craw (Smith and Compere, 1928*c*). This parasite is dark metallic blue-black in color, and about 2 to 3 millimeters in length. The high-arched thorax is characteristic of this species, giving it a humpbacked appearance. The eggs are deposited beneath the adult scale and the larvae feed upon the eggs and newly hatched scales. There are several generations per year. It was thoroughly distributed over California and is now found commonly wherever the black scale occurs. For a time after its introduction it did most effective work, but, as often happens when parasites are introduced, once it had completely adjusted itself to its new environment its beneficial effects as an enemy of the scale was much less than during the first two or three years. Hence its early promise of completely effective control of its host was not fulfilled. The reduction in its efficiency was said to be caused by a severe attack of the predatory mite, *Pediculoides ventricosis* (Newp.), and of certain secondary parasites, which had appeared in California prior to the introduction of *Scutellista* and had subsisted on parasites of the soft brown and perhaps other scales. But the *Scutellista* also has intrinsic weaknesses. The parasite larva, feeding beneath the parent scale, often reaches maturity before it has devoured all the scale eggs present. This results in the escape of large numbers of scales to reinfest the tree. *Scutellista's* effectiveness cannot be judged merely on the basis of the number of scales attacked. The real test of its economic value lies in its ability to prevent a reinfestation the following season; but although it is thus undoubtedly of value, it cannot by itself so far reduce the infestation that no damage will occur to the citrus tree. It has a practical effectiveness, however, where it operates in conjunction with other enemies of the black scale.

*Scutellista cyanea* is an Old World species, accidentally or purposely introduced into many parts of the world now inhabited by it. It is known to occur in Spain, France, Italy, Ceylon, India, China, South Africa, Australia, Hawaii, California, and Louisiana. It attacks a few other scales besides the black scale.

One of the most important internal parasites of the black scale is *Metaphycus lounsburyi* (How.), known to the California growers as *Aphycus.* This little wasp is from 0.7 millimeter to 1.4 millimeters in length and rather pale in color. It deposits its eggs within the body of the scale, where its entire development takes place. It attacks from half-grown to full-grown scales, even

attacking the female scales after egg-laying has commenced. A generation requires approximately thirty days in the summer, and a much longer period in the cooler seasons of the year.

*Metaphycus lounsburyi* was originally described by Howard (1898) from specimens received from C. P. Lounsbury, who reared them from black scale collected at Cape Town. In 1913, several shipments of this parasite were received in California by the author, but it failed to become established from these sendings. In 1917, E. J. Vosler, returning from Australia, where he had been sent to collect leafhopper parasites for the California State Commission of Horticulture, brought with him live black scale from which were reared several individuals of this parasite. These were successfully propagated in the insectary at Sacramento, and in the autumn of 1919 colonies were placed in infested lemon groves at Santa Paula, California. During the following year this parasite did such remarkable work that many thought the black scale problem was solved. Orchards were thoroughly cleared of the black scale and in some of them fumigation was discontinued. At the end of about two years, however, it became evident that *M. lounsburyi* was not so efficient as to permit abandonment of control measures of the mechanical type. Nevertheless, the parasite has rendered valuable service. One very beneficial effect of its introduction was the destruction of "off-hatch" black scale, so that it was possible to time fumigation and spraying much more effectively than before. *M. lounsburyi* also gave much assistance in eliminating the black scale on pepper trees, formerly a frequent source of reinfestation of the citrus groves.

In the interior of California the situation as affecting the efficient use of *M. lounsburyi* was quite different. Here occurs a single uniform generation of the black scale each year, whereas on the coast there is a great deal of overlapping and one may find practically all stages of the scale at any time of year—a condition which had a pronounced effect on the behavior of the parasite. Because of the short life of the adult, *M. lounsburyi,* like most scale parasites, must go through several generations a year in order to exist and must, therefore, find suitable hosts to carry it through these several generations. This it was able to do on the coast, but in the interior there is a long period, from about the first of August until February, when there are practically no scales large enough to serve as hosts, and hence the parasite each year became scarce almost to extinction. It is carried over this period on the few "off-hatch" scales which occur on ornamentals and young citrus trees, but in such small numbers as to preclude its bringing about control of its host. It is true that *M. lounsburyi* often becomes extremely abundant in July in the interior sections, but at this season it breeds on the full-grown female scales which, in spite of this parasitization, are able to deposit large numbers of eggs before they are killed. Heavy parasitization at this season of the year does not, therefore, have any very important bearing on scale control (Smith and Compere, 1928*c*).

Among several species of black scale parasites brought into California from Africa by the University of California in 1937 was *Metaphycus helvolus* (Comp.) (Compere, 1926). This parasite is a small species with orange-colored

females and dark brown males (fig. 196). It has many remarkable characteristics. It is capable of living for long periods as an adult in the orchards—even for more than eight months. This is important, for in many localities its host exists for as long as three months in stages either too large or too small for parasitization by it. *M. helvolus* has an enormous fecundity, being capable of depositing an average of 400 eggs, sometimes as many as 740, per female.

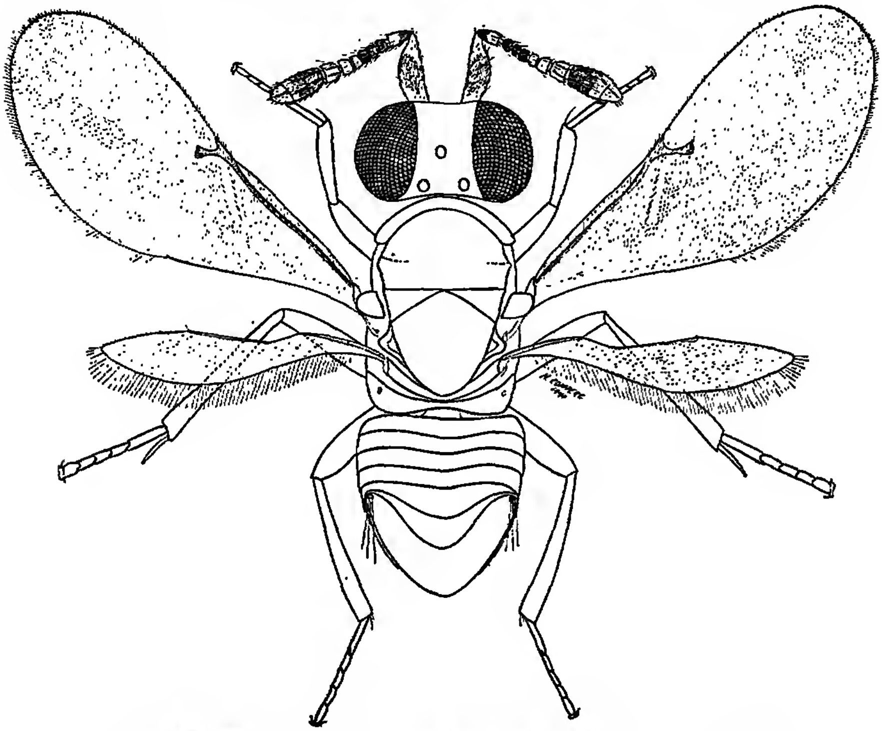

**Fig. 196.** ***Metaphycus helvolus*** **Comp., an effective parasite of the black scale.**

It has great powers of searching and dispersal, as is indicated by its general occurrence in all black scale localities in southern California within less than three years after its introduction. The adult has the extremely important habit of destroying, by host-feeding or sucking, large numbers of host insects in addition to those destroyed by parasitization, thus being a sort of combination of parasite and predator (Flanders, 1942). No other parasite of black scale even approaches *M. helvolus* in these desirable characteristics.

Since the general establishment of *Metaphycus helvolus* in California in 1939, the black scale has been gradually declining in numbers, until, as this is written (1947), the pest is less numerous than at any time since the early days of citriculture. Only occasional groves now require treatment; so few, indeed, as to occasion remark. In the coastal areas, which include all of Santa Barbara, Los Angeles, and Orange counties and most of Ventura and San

Diego counties, black scale populations were less numerous in the years 1943–1946 than in many seasons preceding; so much so, that almost no insecticidal treatment was necessary. In 1947, the number of orchards requiring treatment increased, but this was believed to be only a temporary condition. In certain more interior areas, such as some of the eastern portions of Ventura County, a few medium to heavy infestations occur. In the Highgrove area in Riverside County, and in the eastern part of San Bernardino County, that is, in the San Bernardino–Highland–Redlands area, heavily infested groves are more common. But in southern California as a whole the general picture is one of almost unbelievably low populations of black scale. The downward trend of black scale first became noticeable in 1940; in 1941 it was remarkably low; and in 1944 it was as low as in 1941, if not lower. This coincides with the establishment and spread of *M. helvolus*. The evidence indicates that this parasite is the factor most likely to be the real cause of the low population density of black scale. There is, as mentioned, a relative lack of success of the parasite in certain interior areas. Its ineffectiveness there is related to the extremely even type of development of the black scale characteristic of the hot, arid sections of the citrus belt. In this type of development the seasonal history of the scale is such that for about three months in the summer there are no scale of a size suitable for *M. helvolus* to parasitize. During this time there occurs a high mortality of the adult parasites, so that when the scale are large enough for parasitization in late summer the parasites have largely disappeared. For this reason the reproduction and spread of the species have been retarded in the interior areas (Smith, 1942*a*).

## THE MEALYBUGS

*Pseudococcus* spp.

*The problem and the parasites.*—There are few, if any, important citrus-growing districts in the world in which mealybugs of one species or another do not occasionally become abundant enough to do economic injury. These insects are more difficult to control by spraying or fumigation than any of the other coccid pests of citrus, a fact which has naturally led entomologists to consider and to develop radically different methods for their suppression.

The first attempt at biological control of mealybugs was the introduction into California of the ladybird beetle, *Cryptolaemus montrousieri* Muls., from Australia by Albert Koebele (1893). Some damage to citrus groves was then resulting from the presence of the common mealybug, *Pseudococcus citri* (Risso). The Cryptolaemus beetle became established soon after its introduction, and in the coastal areas has persisted in California ever since. In the early days it often became abundant after a grove had become heavily infested, and it did a thorough job of cleaning up. Generally speaking, however, it was slow in getting into action and a great deal of damage often occurred before it was able to reduce the infestation. As the citrus areas were extended, the amount of damage increased, and in 1914 the California State Commission of Horticulture undertook to relieve the situation by seeking additional insect enemies to prey on the pest. A collector was sent to Sicily, and the little para-

sitic wasp, *Leptomastidea abnormis* (Girault), was discovered and successfully introduced into California (Smith, 1915). This parasite spread rapidly and seemed ideally suited to the California environment. It now occurs abundantly wherever its host is found, and the great reduction in the harm done to citrus by the common mealybug in recent years is in part attributed to its activities, although the extensive production and colonization of the ladybird beetle *Cryptolaemus,* as discussed below, also had a great deal to do with it.

In the propagation of this parasite in the insectary it was found that mealybugs could be grown cheaply on potato sprouts. This discovery led to the attempt to produce the ladybird beetle *Cryptolaemus montrousieri* on a large scale in insectaries for orchard colonization. The work was economically successful against *Pseudococcus citri* (Smith and Armitage, 1931).

Prior to this time, in 1913, the citrophilus mealybug, *Pseudococcus gahani* Green, had appeared in the citrus groves of southern California. This species proved a far more serious pest than *P. citri* had been. It was found that mass production of *Cryptolaemus* and colonization in the groves were fairly effective against this species also.

*Cryptolaemus montrousieri* is a black ladybird with reddish head, prothorax, tips of wing covers, and abdomen. It is about 3 to 3.5 millimeters long. The larvae attain a length of from one-third to nearly one-half inch and are covered with a white, cottony secretion of wax which gives them an appearance very similar to that of mealybugs, particularly before they reach their full size. Growers and other orchard workers often mistake these beneficial larvae for mealybugs and destroy them. With a little experience, however, they may be distinguished at a glance, since the arrangement of the wax or cottony covering is quite different from that of the mealybug, as is also the method of locomotion. The eggs are small, oval in shape, and of a golden yellow color. They are laid usually in the cottony egg sac of the mealybug, or in the vicinity of clusters of the host insects. Although the adults feed upon mealybugs almost exclusively, it is the larvae which are depended upon for the major part of the control work. The species is ideal for this purpose, since it has no secondary parasites in California and does not tend to disperse widely when colonized.

The mass production of *Cryptolaemus* for mealybug control was necessitated because, even though under natural conditions the ladybird would often clean up an orchard, the beetle then practically disappeared because of lack of food. This gave the remaining mealybugs an opportunity to increase again, and serious damage was done before the ladybird was once more in control of the situation. This permitted an alternation in preponderance between the pest and its natural enemies, with the result that the pest did serious damage during certain years. It was believed that if some way could be devised to make available large colonies of this natural enemy, the periodical abundance of the pest could be avoided.

*Methods for mass production of Cryptolaemus.*—The primary requirement in control of pests by this method is a large supply of the natural enemy, available whenever its employment is necessary. This requires a good supply

of the host insect upon which to rear the enemies in quantity. The supply has been obtained by breeding the mealybugs in large quantities on potato sprouts. (See fig. 197.) The discovery of the adaptability of the potato sprout to this work was the main step toward assuring the success of the mass production of *Cryptolaemus*. Investigation shows that the potato sprout is acceptable as a host to all the citrus-feeding mealybugs; it is available throughout the year;

Fig. 197. Cultures of mealybugs on potato sprouts for mass production of beneficial insects.

and its culture is a rather simple matter when close attention is paid to details (Smith and Armitage, 1931).

The mass production of *Cryptolaemus* in California kept pace with the dissemination of the citrophilus mealybug; at one time, fourteen propagation plants were in operation for this purpose. The total production during the 1928 season was more than 42,000,000 beetles, at a cost of between \$2.50 and \$4.00 per thousand. The insectaries were operated by the county governments, local fruit growers' associations, and some of the larger ranches. (See fig. 198.)

On the whole, this work proved fairly successful against the citrophilus mealybug, but as the latter spread more and more widely there was difficulty

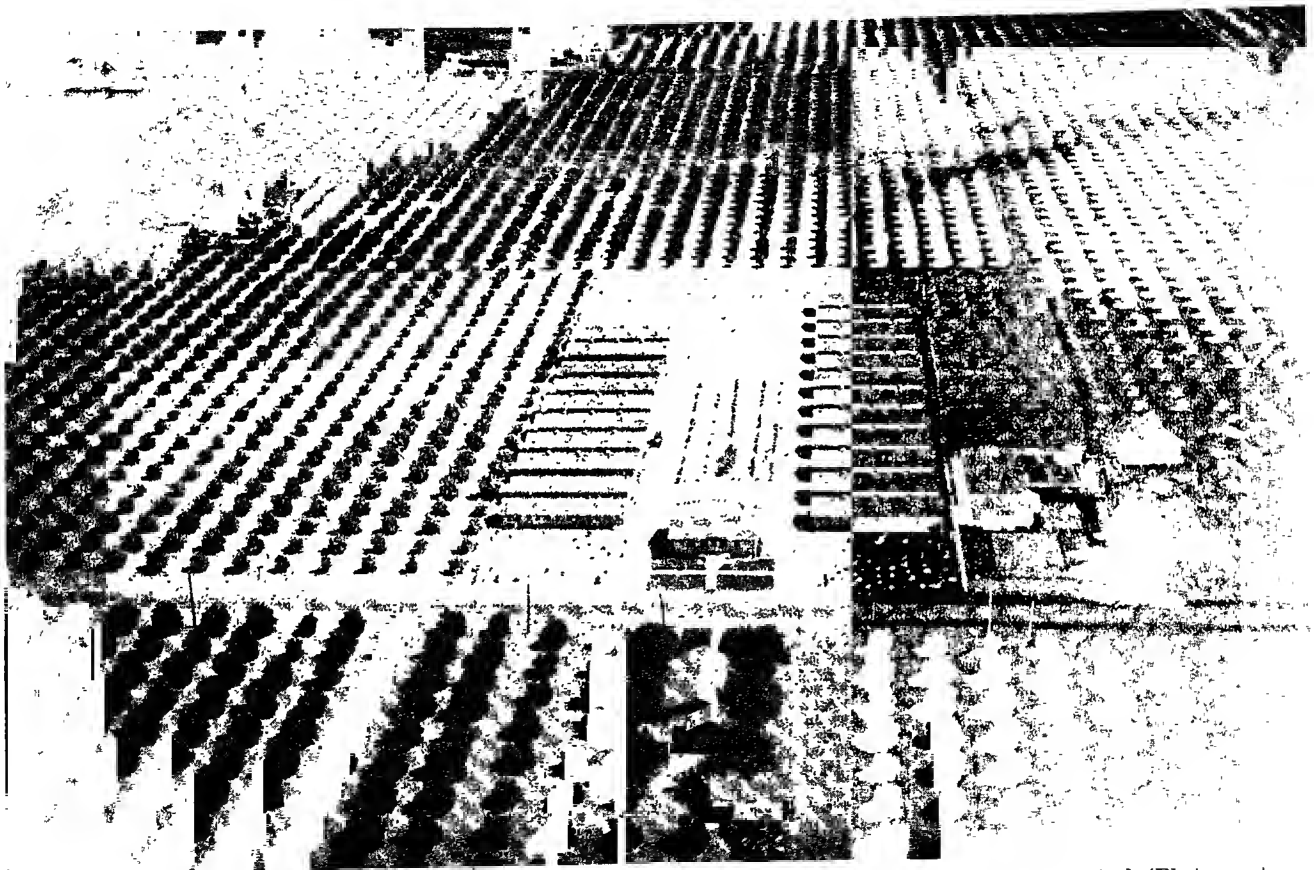

Fig. 198. Orange County Insectary at Anaheim, California, used for growing beneficial insects for citrus pest control. (Photo courtesy of U. S. Army Air Corps.)

in certain areas where *Cryptolaemus,* although colonized in considerable numbers, was not able to keep the pest below the point of economic injury. As these refractory infestations increased, it became evident that something further must be done to protect the growers from serious losses.

*The native home of Pseudococcus gahani.*—The University of California in 1927–1928 made a renewed effort to determine the country of origin of *P. gahani,* and Compere (1928, 1929) found this mealybug in Australia, under such conditions as to make practically certain that it originated there (Smith

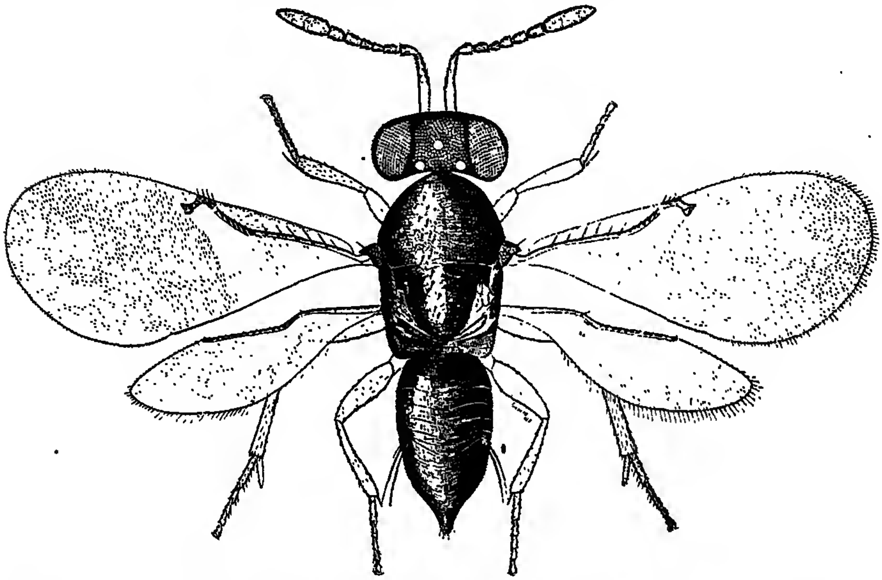

Fig. 199. *Tetracnemus pretiosus* Timb., an effective parasite of the citrophilus mealybug introduced into California from Australia.

and Compere, 1928*a*, *b*). Five species of insect enemies were obtained: two internal hymenopterous parasites, *Coccophagus gurneyi* Comp. and *Tetracnemus pretiosus* Timb. (fig. 199); a ladybird beetle, *Midas pygmaeus* Blackb.; a predatory fly, *Diplosis* sp.; and a green lacewing, *Chrysopa ramburi* Walk. They were all brought successfully to California and were reared and colonized in large numbers by the Citrus Experiment Station and the local insectaries.

The introduction of the parasites *Coccophagus gurneyi* and *Tetracnemus pretiosus* was a great practical success. Heavy parasitization promptly followed their introduction, the citrophilus mealybug began to decline rapidly in numbers, and since 1930 it has been so scarce as to be of no economic importance (Compere and Smith, 1932).

The work of these parasites made it possible to discontinue the propagation of *Cryptolaemus* as a control for citrophilus mealybug, with a resultant saving of more than $100,000 a year in actual cash outlay in the cost of insectary

operation, in addition to a considerable increase in growers' returns by enabling them to hold Valencia oranges on the trees late in the summer when prices were higher. In heavy infestations it had been necessary to pick the fruit early, since otherwise it would drop as a result of mealybug attack (Compere and Smith, 1932). Thus a pest which had become of major importance on more than 50,000 acres of citrus was brought under perfect control by the biological method.

Some of the insectaries are still being operated in order to supply *Cryptolaemus* for use in sporadic outbreaks of *Pseudococcus citri.*

*Other insect enemies of mealybugs.*—Mealybugs as a group seem especially susceptible to attack by insect enemies of various kinds. Their habit of feeding in clusters in unprotected places renders them easily accessible to parasitic and predatory insects. Among the important enemies of mealybugs occurring in California are the brown lacewings or sympherobiids. These insects are generally distributed throughout the infested area and by some entomologists have been considered the most important of the predatory insects attacking particularly the common mealybug. This has not been true recently, however, owing to the extensive propagation of *Cryptolaemus.* The adult brown lacewings are small, about 6 millimeters in length, and are brownish in color, with rather conspicuously netted wings. The eggs are deposited singly within the egg masses of the mealybug or near by, and are pearly white in color. The larvae are dull gray and are rather active in habit. Pupation takes place in a delicate oval cocoon. There are several generations a year, the number depending upon temperature and food supply.

The green lacewing, *Chrysopa californica* Coq., is one of the most important enemies of mealybugs, particularly of *Pseudococcus gahani.* It does not, however, take readily to mass production, and in the open it is severely attacked by internal parasites which greatly reduce its effectiveness. In spite of this difficulty it is of some value, particularly during the colder parts of the year. The adult green lacewing is from 9 to 14 millimeters in length and is bright green in color, with beautiful gauzy wings carried arched over the back when not in use. The eggs are deposited on long stalks. The larvae are provided with long, sickle-shaped jaws, which are very effective. As the larva reaches maturity, a dense spherical white cocoon is spun, usually attached to the bark or some other rough surface on the tree.

In 1921 the ladybird beetle *Scymnus binaevatus* Muls. was successfully established in California, having been introduced from Cape Town, South Africa. This insect is distinct in appearance from any of the other species occurring in California by reason of its greatly elongated body. It is blackish in color, with a brown spot on each wing cover. The larvae are covered with a white, cottony secretion. This little beetle became valuable in the control of *Pseudococcus gahani* because of its habit of searching in crevices for mealybugs which were likely to escape attack by other natural enemies. It is distributed throughout the coastal area of southern California (Smith, 1923).

In 1934, *Leptomastix dactylopii* How., a parasite of the common mealybug, *P. citri,* was introduced into California from Brazil by the University of Cali-

fornia (fig. 200). By the end of 1935 more than 4,000,000 individuals of this parasite, each a descendant of the single pair imported from Brazil, had been propagated in the insectaries and released in the citrus orchards of California (Compere, 1939). This species has given effective assistance in the control of

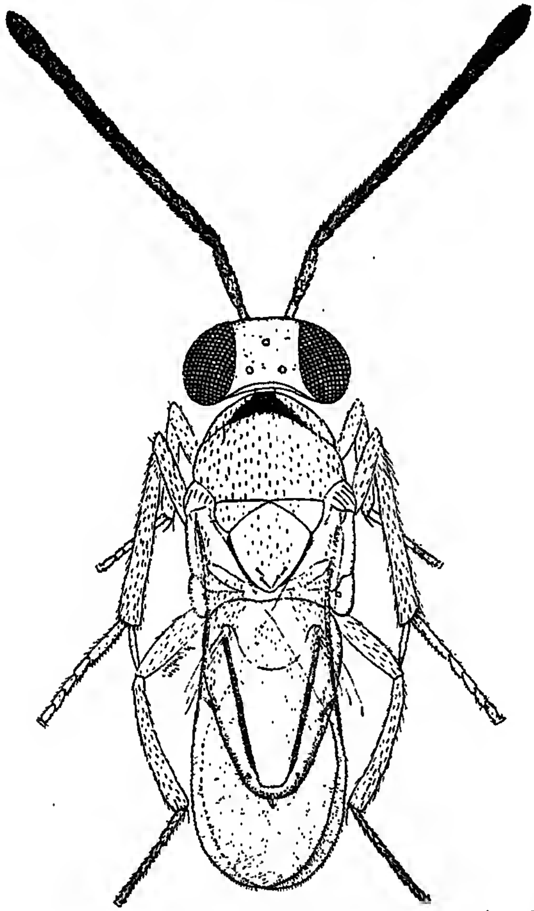

Fig. 200. *Leptomastix dactylopii* How., a parasite of the common mealybug imported from Argentina by the University of California.

the common mealybug, *P. citri,* in Ventura County, and the Associates' Insectary, a growers' coöperative of that county, regularly propagates and distributes several million of this species annually.

The long-tailed mealybug, *Pseudococcus longispinus* (Targ.), ordinarily not a pest of citrus, became very injurious on a few hundred acres in 1932 and 1934 in Los Angeles County. Three different species of parasites were established on this pest by the University of California (Flanders, 1940). These

are *Anarhopus sydneyensis* Timb. and *Anagyrus fusciventris* (Girault) from Australia, and *Tetracnemus peregrinus* Comp. from South Africa.

There are many other species of predatory and parasitic enemies which attack mealybugs in California, but their economic importance is not great enough to justify discussion of them here.

*Mealybug control in countries other than the United States.*—In Spain, a great deal of experimental work in biological control has been carried out at the Experiment Station at Burgasot (Valencia) against *Pseudococcus citri,* and the methods developed in California for mass production of *Cryptolaemus* have successfully been put into practice on a large scale (Gomez Clemente, 1932).

In France, an insectary was established at Mentone for the purpose of developing this method of control, and *Cryptolaemus* has been successfully established there (Poutiers, 1922).

A detailed study of the use of insect enemies in control of the common mealybug, *Pseudococcus citri,* has been made in Palestine and it is reported (Bodenheimer, 1928) that a measure of practical success has resulted. So far as *Cryptolaemus* is concerned, it is stated that the biological control of *P. citri* with *C. montrousieri* has, for climatic reasons, been ineffective in Palestine. Good results are said to have been obtained, however, by the use of *Sympherobius amicus* Nav., one of the brown lacewings.

Within recent years another citrus-feeding mealybug, suspected of being *Pseudococcus citriculus* Green, has become exceedingly injurious to citrus in Palestine. This pest is a native of the Orient, and a project was initiated by the Palestinian citrus growers to introduce parasites for its control from Japan and China. Some material was transported to Palestine, but the project was interrupted by Japanese participation in the war. One report (Rivnay, 1942) indicates that encouraging results have been obtained from these introductions of Japanese parasites.

For fungus parasites of mealybugs see pages 647–648, below.

### THE YELLOW SCALE

*Aonidiella citrina* (Coq.)

In 1924–1925 the University of California succeeded in establishing the parasite *Comperiella bifasciata* How. (fig. 201) in the State (Compere and Smith, 1927). The stock from which the liberated parasites descended came from Japan, where they attacked a scale on *Podocarpus,* then thought to be the California red scale, *Aonidiella aurantii* (Mask.), but now known to be *A. taxus* Leon. Repeated trials of this parasite on the California red scale made it quite evident that the Japanese parasite could not develop successfully on that host. It was established in California on another species, *Chrysomphalus bifasciculatus* Ferris, on *Aspidistra.* Later on, in the course of experimental work, it was found that this Japanese parasite could develop successfully on the yellow scale. The parasite was then propagated and colonized in large numbers in areas where the yellow scale occurred. It has been well established in California citrus groves since 1931. In the Redlands–San Bernardino area

it appears to do good work, although the use of control measures for other pests reduces its efficiency. In Tulare County, where the yellow scale is increasing in severity, *Comperiella* appears to be erratic, although giving good control on street trees and apparently in some grove acreages. In other groves, trees have been almost defoliated by yellow scale although *Comperiella* was present in large numbers; apparently, the parasite was not able to keep the infestation below the danger point.

There is no doubt that *Comperiella* has done good work in places, but that it will prove *generally* effective on the yellow scale seems, at this time, very unlikely.

Two other parasites of the yellow scale are *Aphytis chrysomphali* (How.) and *Aspidiotiphagus citrinus* (Craw.), which are practically cosmopolitan in

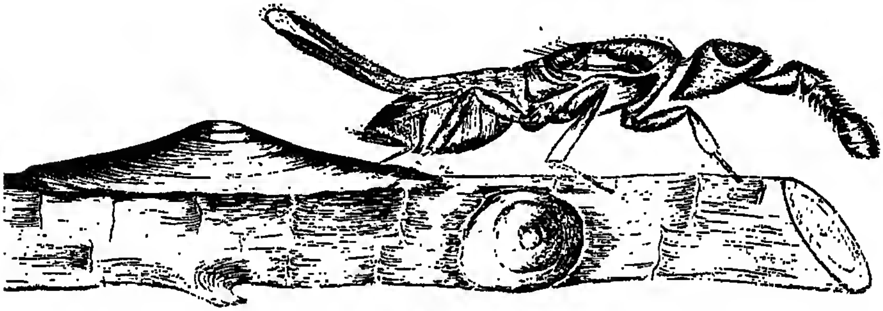

Fig. 201. *Comperiella bifasciata* How., a parasite of the red and yellow scales imported from Asia by the University of California.

distribution. Although in heavy infestations, particularly on street trees, they sometimes destroy large numbers of yellow scale, it cannot be said that either is an important factor in reducing the pest under orchard conditions.

THE RED SCALE
*Aonidiella aurantii* (Mask.)

The quest for effective enemies of the red scale by the State of California has been long and disappointing, dating back to the time of Koebele's second trip to Australia in 1891. Koebele succeeded in establishing in California the Australian ladybird beetle *Orcus chalybeus* (Boisd.), which does good work in parts of Santa Barbara County but seems unable to survive in most other parts of the State. In California, besides *O. chalybeus,* the native twice-stabbed ladybird *Chilocorus bivulnerus* Muls. sometimes destroys large numbers of red scale. In the Mediterranean region the diaspine scales of citrus are commonly attacked by two predators, *Chilocorus bipustulatus* (L.) and *Exochomus quadripustulatus* (L.), the second of which is now established in northern California.

In 1935, W. K. Roux discovered in South Africa a parasite of the red scale which was described by Compere (1936) as *Habrolepis rouxi*. This parasite was successfully brought into California, where insectary experiments indi-

cated that it was well adapted to propagation on the red scale. Hundreds of thousands were easily reared and colonized in the citrus groves. But *Habrolepis* proved a great disappointment. For some unknown reason it does not succeed in maintaining itself on the citrus tree. The usual experience was that it went through a single generation on the colonized trees and then disappeared. It seems evident that although *Habrolepis* likes the red scale as a host it does not like the citrus tree as a habitat, and leaves it at the first opportunity. An exception occurs in Sweetwater Valley, San Diego County, where the parasite has persisted for several years (Flanders, 1944).

The parasite *Comperiella bifasciata* How., as previously mentioned under "The Yellow Scale," was discovered by George Compere in China as a parasite of what he thought to be red scale. The introduction of this parasite from Japan and its failure to breed on the red scale in California seemed to justify the conclusion that the so-called red scale in China was a different species, or at least a distinct race, from the California form, although taxonomic specialists could find no morphological differences.

Several attempts were made to rear *Comperiella bifasciata*, already well established in California on the yellow scale, on the red scale. These failed to produce results, but it must be remembered that the breeding stock of *C. bifasciata* came from Japan on a scale infesting *Podocarpus*. Parasitized red scale from China on citrus was unavailable because of the danger of bringing in citrus canker. Various considerations, which for lack of space cannot be discussed here, but which the interested reader will find discussed elsewhere (Smith, 1942*b*), made it seem essential to bring in parasitized red scale from China. The fear of citrus canker still prevailed, and, in order to avoid danger, arrangements were made with the United States Bureau of Entomology and Plant Quarantine to receive the material at Hoboken, examine the plants for canker, rear out the adult parasites, and send them on to California. It was soon demonstrated that the *Comperiella bifasciata* originating in China develops with the utmost facility on the California red scale (and the yellow as well) and that it is a race genetically distinct from the *C. bifasciata* originating in Japan and previously established in California on the yellow scale.

Failure to establish this parasite in California during the long period 1906–1924 was due to (1) gaps in the available knowledge of the genetics of insect parasites, (2) uncertainty concerning the true identity of various scales which, in the Orient, were all subsumed under the name *Aonidiella aurantii*, (3) failure to appreciate that certain host plants could confer on their insect inhabitants an immunity to parasitization, (4) the need of exercising extreme care to keep dangerous plant diseases out of the State, and (5) slowness of transportation.

*C. bifasciata* was propagated, in millions, on the red scale by the University of California and coöperating local insectaries. It appears to be established in the open, but information about its economic value in the citrus groves must of course await several years of field experience.

For fungus and bacterial diseases of red scale see pages 638 *ff.* and 654.

### THE PURPLE SCALE
*Lepidosaphes beckii* Newm.

This scale is almost universally attacked by the internal parasite, *Aspidiotiphagus citrinus* (Craw.), and also by numerous ladybird beetles and other predators throughout its range. In the Orient a species of *Casca* is also parasitic in this scale. For fungus parasites of the purple scale see pages 638 ff.

### THE SPANISH RED SCALE
*Chrysomphalus dictyospermi* (Morgan)

This scale is attacked in the Mediterranean region by *Chilocorus bipustulatus* (L.) and *Exochomus quadripustulatus* (L.), and by the parasites *Aspidiotiphagus lounsburyi* Berlese and Paoli and *Aphytis chrysomphali* (Mercet). and in the Orient by *Comperiella bifasciata* How. and *Chilocorus kuwanae* Silv. (Silvestri, 1929).

### THE SOFT BROWN SCALE
*Coccus hesperidum* Linn.

The soft brown scale is attacked in various parts of the world by a large number of parasitic insects, many of which undoubtedly have followed their host from country to country on shipments of nursery stock. As a rule, they keep the scale well in check. When the scale becomes numerous, it is almost invariably found that its abundance is due to the protection afforded by colonies of ants. In California, ant control will almost without exception rid citrus groves of this scale. The principal parasites attacking the soft brown scale in California are *Coccophagus lycimnia* (Walk.), *C. scutellaris* (Dalm.), *Metaphycus luteolus* (Timb.), *M. stanleyi* Comp., and *M. helvolus* Comp. (Timberlake, 1913).

### THE CITRICOLA SCALE
*Coccus pseudomagnoliarum* (Kuwana)

The citricola scale is attacked in California by the same species of parasites that parasitize the soft brown scale, but against this pest they have had very little effect. (Recently, *Metaphycus helvolus* and *M. stanleyi* appear to be attacking it heavily in some localities.) The reason for their ineffectiveness is that the citricola scale has only a single generation a year, as contrasted with the soft brown scale, which has several. Since the habits of the parasites are such that they must go through several generations a season in order to survive in numbers, and since there are long periods of time during which the citricola scales are not of the proper size to permit parasitization, the parasites are ineffective as a result of the faulty synchronization. The parasites are effective against the soft brown scale, which has several generations a year, because the generations of the parasites are uninterrupted (Compere, 1924).

In Japan the citricola scale is attacked by *Coccophagus japonicus* Comp., *Aphycus orientalis* Comp.. *Coccophagus yoshidae* Nakayama, and *Anicetus annulatus* Timb. Some of these species have been introduced into California

to prey upon the citricola scale, but, so far as is now known, none of them has become established (Compere, 1924). For a possible bacterial disease of citricola scale see page 655.

THE CITRUS WHITE FLY
*Dialeurodes citri* (Ashm.)

The citrus white fly seems to be comparatively free from insect parasites. Woglum (1913) records an internal parasite, *Prospaltella laborensis* How., from India. The introduction of this parasite into Florida was attempted by the United States Department of Agriculture, without success. Silvestri (1927) records rearing the parasite *Prospaltella citrofila* Silv. from this species in Indo-China. It is preyed upon in India by a species of *Cryptognatha*, and in Florida by various native species of ladybird beetles. For fungus parasites see pages 631–638.

THE CITRUS BLACK FLY
*Aleurocanthus woglumi* Ashby

The biological control of this important citrus pest in Cuba was begun in 1930 by the United States Bureau of Entomology and Plant Quarantine in collaboration with the Cuban government (Clausen and Berry, 1932). The parasite *Eretmocerus serius* Silv., discovered by F. Silvestri (1927) while he was in Asia in search of parasites of the red scale for the University of California, is recorded in the literature as a parasite of the citrus black fly. C. P. Clausen went to Malaya in 1929 and brought back, in April, 1930, citrus black fly parasitized by *Eretmocerus*. He also brought two other parasites, *Prospaltella divergens* Silv. and *P. smithi* Silv. The two species of *Prospaltella* failed to become established, but *Eretmocerus* soon demonstrated its effectiveness. Infestations throughout Cuba were quickly brought under control, and later the same result was achieved in Jamaica, Panama, Haiti, and other countries and islands where *Eretmocerus* was established, with the single exception of a few citrus groves at Nassau in the Bahamas. The reason for its failure at Nassau is not known. There was also established in Cuba the coccinellid predator *Catana clauseni* Chapin, also from Malaya. This beetle, like many other coccinellids, can reduce heavy infestations of its prey very quickly, but it is unable to *keep* the black fly at a permanent low density, its presence resulting rather in oscillations of the host population.

In recent years the citrus black fly has appeared on the west coast of Mexico. Introduction of the parasite *Eretmocerus serius* seems not yet (1947) to have effected successful control.

THE SPINY BLACK FLY
*Aleurocanthus spiniferus* Q.

This insect, also a native of Malaya, was accidentally introduced into the citrus-growing areas of Japan and was discovered in 1922, after which time it increased rapidly and did serious damage. The parasite *Prospaltella smithi* Silv., found by Silvestri (1927) in Malaya, was introduced into Japan in

1925 from South China. According to Kuwana (1934), the introduction resulted in complete control of the pest.

### THE MEDITERRANEAN FRUIT FLY
*Ceratitis capitata* (Wied.)

The Mediterranean fruit fly is attacked by large numbers of parasites in its native habitat, Africa (Silvestri, 1914). Several of these parasites have been introduced into Hawaii (Pemberton and Willard, 1918*a*, *b*) and have become established. They are effective on small host fruits such as coffee berries, but not on large ones such as oranges, peaches, etc., because in the large fruits the larva of the fly is able to burrow beyond the reach of the parasites and thus is in large measure protected from attack by them. The reduction in fruit-fly population on wild fruits by these parasites has undoubtedly been of great value, however, in the protection of commercial cultures. The most important parasites introduced into Hawaii are *Diachasma tryoni* Cam., *D. fullawayi* Silv., and *Tetrastichus giffardianus* Silv. In the Hawaiian Islands the fly is also attacked by the ant *Pheidole magacephala* Fabr.

### THE CITRUS MITES, ACARINA

Several species of mites attack citrus in various parts of the world, the principal ones in the United States being the citrus red mite, *Paratetranychus citri* McGregor; the six-spotted mite, *Tetranychus sexmaculatus* Riley; the citrus bud mite, *Eriophyes sheldoni* Ewing; and the citrus rust mite, *Phyllocoptes oleivorus* (Ashm.). They appear to have no true parasites, but some are attacked by a series of predaceous insects. Among the more abundant of these are *Conwentzia hageni* Banks, a coniopterygid; the brown lacewings, belonging to the family Hemerobiidae; the green lacewings, or Chrysopidae; *Oligota oviformis* Casey, a staphylinid beetle; the coccinellid, *Stethorus picipes* Casey; *Scolothrips sexmaculatus* (Pergande), a predatory thrips; a predaceous midge, *Arthrocnodax occidentalis* Felt., of the family Cecidomyiidae; the bug *Triphleps tristicolor* White, an anthocorid; and a predatory mite, *Seiulus* sp.

In heavy infestations these enemies of mites become very abundant and undoubtedly reduce in some degree the intensity of the infestation, particularly where fumigation and spraying are not extensively practiced. But as a rule, when meteorological conditions are favorable, the mites are able to increase so rapidly, as compared with the predatory insects, that the latter cannot be said to be of great protective value (Quayle, 1932, 1938). For a fungus parasite of rust mite see pages 649–650.

## ANTS IN RELATION TO BIOLOGICAL CONTROL

It is now generally accepted that in order to make effective use of the biological method it is often necessary to eliminate ant infestations from the groves, because various species of ants which feed upon the honeydew excreted by certain scale insects protect them from attack by parasitic and predatory species. Where heavy ant infestations occur, particularly of the Argentine

ant, it is difficult to gain satisfactory results by the biological method, and disposal of the ants is therefore necessary.

The method now practiced in California is limited to the use of poison syrup.[1] Briefly, the operation consists in attaching to the trunk of the tree a container partly filled with the syrup. The proportion of arsenical in the syrup is not sufficient to kill the workers at once, but permits them to carry the poison into the nests, where they feed it to the queens and larvae, thus destroying the colony in the nest. When this is done, the workers gradually disappear.

Many types of containers are now in use. One of the most satisfactory, which is used by the agricultural commissioner of Los Angeles County, California, is made of pressed aluminum.

The Argentine ant is most active in the spring and fall, and those are therefore the best seasons for undertaking control measures. It is desirable that control work be undertaken as a community project, in order to prevent reinfestation from surrounding areas, although the individual grower will be well repaid for his work even though he undertakes it independently. If the syrup is accurately compounded and the proper containers are used, ant control is not difficult. Care must be taken that the cups do not leak, permitting the syrup to drip on the bark, as this will cause gumming. The containers should be inspected regularly, and if the syrup becomes fouled by drowned ants, or from other causes, it should be replaced with a fresh supply.

The agricultural commissioner of Los Angeles County has been successful in executing a large-scale community project for ant control. The campaign was first undertaken on 6,485 acres of citrus property. In two years' time the Argentine ant appeared to have been exterminated in half this area and was effectively reduced in the remainder. There were 14,200 acres in the area under inspection, and the total cost of the campaign was $13,567.53, or somewhat less than $1.00 per acre. If the cost had been assessed against the infested property only, it would have amounted to about $2.00 per acre. In this work, each district exchange of the California Fruit Growers' Exchange guaranteed to the county agricultural commissioner the cost of all labor and materials used in that district, regardless of ownership. This is an excellent example of what can be accomplished in pest-control work with proper organization and coöperation (Ryan, 1928).

[1] The ingredients of poison bait for control of the Argentine ant are 11 pints water, ¼ ounce tartaric acid, ⅓ ounce benzoate of soda, 12 pounds granulated sugar, ¾ ounce chemically pure sodium arsenite, and 2 pounds strained honey.

Heat the water until lukewarm. Add the tartaric acid and stir until dissolved. Add the benzoate of soda and stir until dissolved. Slowly add the granulated sugar, stirring constantly until dissolved. Note the exact height of the liquid in the container, cover, and boil slowly for 40 minutes. At 20-minute intervals add water to equal the amount evaporated. To 1 pint of lukewarm water add the sodium arsenite and stir until completely dissolved; then add this to the syrup and stir well. Finally, stir in the honey.

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## Chapter XIII

# BIOLOGICAL CONTROL OF CITRUS INSECTS BY PARASITIC FUNGI AND BACTERIA

BY

HOWARD S. FAWCETT

A large number of fungi and at least two species of bacteria have been described as parasitic on citrus insects. It is probable that many more species of bacteria, and viruses also, will eventually be found to produce diseases in insects of citrus.[1] Although many of the fungi have been considered important for partial or seasonal biological control under certain natural conditions, only a few have so far been used artificially as means of control. These few have not been depended upon for continuous satisfactory control except under conditions unusually favorable for the development of the entomogenous parasites, or where the cost for a high degree of commercial control by spraying was greater than would be justified by the increased returns.

In comparison with the investigations of entomophagous parasites (insects parasitic on other insects), the experimental work on entomogenous parasites (fungi or bacteria parasitic on insects) in relation to biological control has received relatively little attention, and, except for studies of a few microorganisms, has not gone much beyond observation and description. Only a relatively small number of well-controlled experiments have been carried out, perhaps because in the recent period of extreme specialization this subject has become a kind of "no man's land" between the entomologist's field of study and that of the plant pathologist and applied mycologist. Mycologists, however, have in the meantime added descriptively to our knowledge of the occurrence and morphology of these entomogenous fungi.

One apparent cause for neglect of the field has been the hasty generalization that failure to achieve outstanding results with certain fungi in initial trials means that there is little promise of practical results. Another is probably the preoccupation of both entomologist and plant pathologist with problems which they have thought more closely related to their special fields.

The literature on entomogenous fungi and bacteria is widely scattered. Petch (1914 to 1939) has collected a large amount of information, especially on the taxonomic relationships of entomogenous fungi. Most of his papers will be found in the *Transactions* of the British Mycological Society from 1921 to 1939 and in *Reports* of the Department of Agriculture, Peradeniya, Ceylon. Other sources, some of which have large bibliographies, are Parkin

[1] Sweetman (1936) lists about 40 species of bacteria that are generally thought to cause diseases in insects. Steinhaus (1940, 1942) reports about 350 species of bacteria found in association with 300 species of insects and ticks, only some of which are thought parasitic. A number of viruses have also been recognized as diseases of insects (Glaser, 1915, 1927; Sweetman, 1936; Balch, 1941, 1942).

(1906), Fawcett (1908, 1936, 1944), South (1910), Speare (1912, 1920, 1922), Morrill and Back (1912), Rolfs and Fawcett (1913), Berger (1910, 1912, 1921, 1932, 1942), Watson (1914*b*), Watson and Berger (1937), Gösswald (1939), Paillot (1922), Masera (1936), and Steinhaus (1940, 1942, 1946).

A large number of fungi found on insects in general are mentioned by Masera (1936), and a comprehensive list of fungi found on insects in North America has been compiled by Charles (1941). Lists of bacteria found in and upon insects have been compiled by Paillot (1922) and Steinhaus (1940, 1942, 1946).

## GENERAL CONSIDERATIONS

In biological control of insects two opposing forces of survival, already pointed out by Chapman (1931, 1939), come into play: (a) *biotic potential*, or inherent ability of the insect to reproduce and survive, and (b) *environmental resistance*, or the physical and biological factors that oppose survival. The parasitic fungi and bacteria constitute a part of this environmental resistance to insect survival, a small or large part in accordance with the degree of parasitism and the physical conditions influencing distribution and infection. Since opposing forces of *biotic potential* and *environmental resistance* are also operating on the fungi themselves, the insect's resistance to infection may be considered a part of the *environmental resistance* for the fungus. Biological control of insects, especially as related to entomophagous parasites, has been discussed by Smith (1929, 1935, 1939), Thompson (1930), and Sweetman (1936).

### GRADATION OF PARASITISM

The gradation of parasitism, conditions influencing effectiveness, conditions influencing the saturation point, and artificial use in control have been discussed in some detail elsewhere (Fawcett, 1944). In parasitism of insects, as in that of plants, there is apparently a gradation from the strongest and most complete parasites down to those which are very weak and indirect. It is therefore unsafe to draw conclusions about the efficiency of the entomogenous fungi as a whole from a few examples, such as the chinch-bug fungus, most often referred to in publications on biological control. Four categories of fungus parasitism on insects may be mentioned, with examples from citrus insects:

1) Parasites which propagate only on or within the body of the live insect, such as *Sorosporella* and *Empusa*. As soon as the insect dies, they usually form resistant resting bodies or spores which will propagate again only when they come in contact with another live insect.

2) Fungi that are parasitic during a part of their existence, such as *Aschersonia, Aegerita,* and *Nectria,* which may enter and kill the insect when the spore or fungus mycelium comes in contact with the insect under suitable conditions, but which may also live a saprophytic existence on the bodies of the insects after their death. Some fungi of this second kind may kill the insect more rapidly and be more effective in epidemics than some of the obligate parasites.

3) Weak parasites, such as *Cephalosporium,* which appear to depend, for infection and propagation, on a special stage or weakened condition of the insect.

4) Fungi, mostly symbiotic, that are partly parasitic, such as some species of the genus *Septobasidium,* which appear to have for the most part a symbiotic relationship to certain scale insects (Couch, 1938), but which at times appear to parasitize the insects.

A fifth category cannot be considered as parasitic at all since the fungi live only as saprophytes on the bodies after the insects have died. Most of the species of *Cladosporium,* some of which are found on citrus insects, are thought to be of this class, although some *Cladosporium* species may possibly be semiparasitic on insects under certain conditions.

## CONDITIONS INFLUENCING EFFECTIVENESS

Although a number of these parasitic entomogenous fungi develop, under favorable conditions, conspicuous pustules or sporulating structures after they have killed the insect by invasion of the bodies, this development of conspicuous evidence of their presence may be arrested by drying conditions following infection so that the insect bodies are desiccated or rendered unfit to support the later development of the fungus. Thus, what is often referred to by observers without careful microscopic examination as ''natural mortality'' or ''unexplained mortality'' may be due to early stages of fungus attack which is not visible even with a hand lens. Other ''unexplained mortality'' may result from the activities of parasites which live internally and rarely if ever show on the exterior.

Moisture, temperature, degree of light, mode of distribution, and nutrition of host or parasite may influence the effectiveness of these entomogenous fungi under natural conditions (Fawcett, 1944).

The efficiency of fungus parasitism, like that of insect parasitism, can be increased by artificial means. Certain considerations, however, must be taken into account, as follows:

If the conditions for distribution of the fungus are such that the maximum number of spores infect the maximum number of insects under the prevailing environmental conditions, no added results can be expected from artificial distribution unless the conditions are changed. A relationship of this kind may be called the ''saturation point'' for insects and fungi. ''Saturation'' was probably the relationship of *Beauveria globulifera* with the chinch bug during the experiments of Billings and Glenn (1911), when no increased mortality resulted from distribution of additional spores. A saturation point might be expected most of the time from the abundance of wind-borne spores which such a fungus is capable of producing.

When conditions are such that distribution is inefficient, that is, when distribution is retarded or remains below the ''saturation point'' for maximum infection under the prevailing conditions, artificial distribution may be expected to increase the degree of infection. Whether artificial distribution would constitute an economical measure of control would depend, as it does

with the use of entomophagous insects, upon what degree of increase could be effected by this means and what its cost would be. It is believed that the natural distribution of a number of these fungi often lags far behind possible infection. For example, in Florida the aphis fungus *Empusa fresenii* appears to depend for infection on contact with spores and has to wait, under natural conditions, for the time of insect migration. Artificial distribution preceding migration might be of assistance.

## CONDITIONS INFLUENCING THE "SATURATION POINT"

It is pointed out by Watson and Berger (1937) that in Florida after a dry period, or after a dry season the previous year, the *Aschersonia* and *Aegerita* are not numerous enough to infect citrus white-fly larvae efficiently unless they are distributed artificially at the beginning of the summer rainy period, usually in June or July.

As with insect parasites on insects, so with fungus parasites when the saturation point has been reached for natural infection under a given set of conditions, there is still some possibility of artificially manipulating or changing the natural conditions in order to increase infection. Changes may be made in humidity by overhead irrigation to increase the moisture on the surface of leaves or fruits for a short time, or by other devices such as the growing of intercrops. The latter method has been suggested in Florida for increasing the efficiency of the aphis fungus, *Empusa fresenii* (Tisdale, 1930). With fungus disease on plants it is known that rapid weather changes greatly increase or decrease infection.

Another possible factor is the increase or decrease of an insect's susceptibility to infection by its parasite because of changed nutritional conditions of the host plant. See mention below (p. 654) concerning the bacterium of the citrus red scale (Sokoloff and Klotz, 1943).

It must be pointed out that finding an organism generally distributed in a given locality does not certify that the saturation point for infection has been reached. This point may be reached at one season and not at another. Moreover, in many organisms, the fungi or bacteria of common plant and animal diseases, it has been shown that the amount of infection may be greatly increased by the nature of the inoculum. The density and size of the inoculum of bacteria, or the "spore load" of fungi, is of great importance in breaking down resistance to infection (Heald, 1921).

## ARTIFICIAL USE IN CONTROL

In attempts to increase the control of insects on citrus, only a few of the entomogenous fungi have been artificially distributed, mainly in Florida, and they are usually employed only as a supplementary aid. As Berger (1921) states, their use is recommended not "as a panacea but principally as an aid in the control of scales and white fly." The fungi do not thrive in all kinds of localities, nor under all grove conditions. The methods used for distribution of the organisms will be mentioned under the discussion of the various species or groups.

The future possibilities of their use would seem to depend, as with respect to insect parasites on insects, upon (1) devising efficient, economical methods of spread when there is an unsaturated condition of infection; (2) devising economical means of changing the environment on or about the plant so as to increase infection, that is. to shift the saturation point so that the organisms present or those being applied may have better conditions for infection: and (3) changing the nutrition of the plants (and concurrently the nutrition of the insects) so as to make them more susceptible to infection by the parasitic organisms present or being applied.

Further general considerations are discussed by Fawcett (1944) and Watson (1944).

## FUNGI OF CITRUS WHITE FLIES

At least five species of fungi occur commonly in Florida on the larvae of the two common species of *Aleurodes*, the citrus white fly and the cloudy-winged white fly;[1] and a number of others occur less frequently. The five species are the red Aschersonia, ***Aschersonia aleyrodis*** Webber; the yellow Aschersonia, *A. goldiana* (S. and E.); the brown fungus, ***Aegerita webberi*** Faw.; the white-fringe fungus, ***Fusarium aleyrodis*** Petch; and the cinnamon fungus, ***Verticillium cinnamomeum*** Petch. A sixth, ***Sporotrichum*** sp., has also been isolated from adult white flies (Fawcett. 1908). Other, less important, fungi occurring on various white flies are mentioned later. It has been suspected that certain bacteria may also be parasitic on white flies, but no observations except a minor one by Watson (1913) have been reported.

When these organisms are present in moist, shaded locations in the low hammocks of Florida and semitropical countries, the white flies are practically controlled during some years.

Although Morrill and Back (1912) conclude that in most citrus orchards in Florida the natural control cannot be relied upon, they state: "There are, however, certain circumstances under which fungous parasites may be used to advantage. First may be mentioned the comparatively few citrus groves located in hammocks, with trees growing without regularity and with conditions such that fumigation or spraying with insecticides would be impracticable."

The different conclusions reached in experiments (1) by Morrill and Back (1912), who found no conclusive evidence that mortality of white-fly larvae could be markedly increased by artificial distribution or by spraying with spores where the fungi were already present, and (2) by Berger (1910, 1921, 1932), who found good evidence that it could be increased greatly by spraying spores at the proper season, may possibly be explained on the following assumption. Morrill and Back probably experimented at a time when the "saturation point" for infection was nearly reached: Berger, probably at times of unsaturation or of lag in possible infection for the prevailing conditions.

[1] For scientific names of insects mentioned here by their English names see table 49, p. 657.

The use of these fungi to increase natural control has been practiced chiefly in Florida. The principal methods developed have consisted in simply spraying a suspension of the spores in water into trees infested with the insects. Some times the fungus-bearing leaves were pinned to fungus-free leaves; at other times, twigs containing fungus-bearing leaves were tied into branches of trees that were fungus-free. The brown fungus of the white fly, *Aegerita webberi* Faw.—soon after it had been discovered and before it had spread widely, —was sometimes spread by placing young fungus-bearing trees so that their branches would intermingle with fungus-free branches of other trees. The spores to be sprayed were derived either from leaves containing numerous well-developed pustules of the fungi or from pure cultures containing numerous spores. The moist summer season, according to Berger (1921), was the most effective period for parasitizing the insects with spore suspensions.

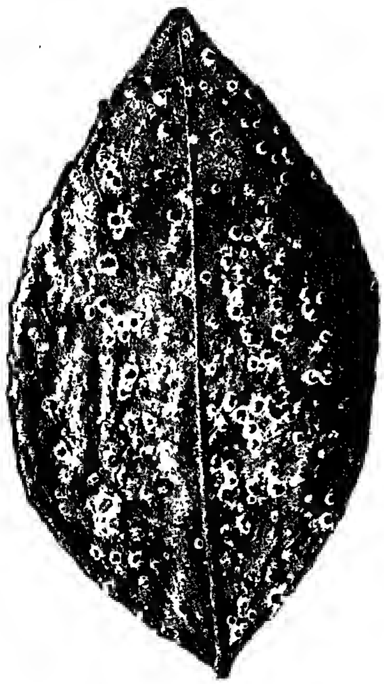

Fig. 202. The red Aschersonia fungus, *Aschersonia aleyrodis*, on white-fly larvae of *Dialeurodes citri*. The fungus pustules have a central mass of red surrounded by a white margin over the larvae after being killed by the penetration of the hyphae.

RED ASCHERSONIA

Red Aschersonia, *A. aleyrodis* Webber.[1]—This fungus is parasitic on larvae of species of white flies in Florida, Brazil, the West Indies, South China, India, and Ceylon. It occurs commonly on the citrus white fly and the cloudy-winged white fly; and has also been reported (Watson and Berger, 1937) on other white flies that occasionally infest citrus, such as woolly white fly, sweet potato white fly, and mulberry white fly in Florida, and citrus black fly in Cuba, Jamaica, and Costa Rica. It is also reported on the black parlatoria scale in Formosa.

*Aschersonia aleyrodis* Webber forms a raised, flattened, pulvinate, red to pinkish buff, stromatic pustule 1 to 2 mm. in diameter on the surface of the leaf (fig. 202). The spores are immersed in cavities of the pustule and are about 9 to 14$\mu$ long and about 2 to 3$\mu$ broad.

This fungus was discovered and described by Webber (1897), who found that although larvae of all stages were readily attacked, the most numerous victims were the young. The tortuous, flexuous, intricately woven hyphae may be seen within the

[1] The perfect stage is now considered to be *Hypocrella libera* Syd. (Petch, 1925*d*).

body. In early stages while larvae are still alive they become swollen and appear to secrete more honeydew than usual. After the fungus develops internally but is still not visible on the exterior, the interior organs appear to contract from the margin. Soon afterward, a dense marginal fringe is formed by the hyphae bursting out from the interior around the edge of the larvae (fig. 203, *B*, *C*). The larvae die, it is believed, before the hyphae burst out. The visible pustule with its spores develops later (fig. 203, *C*).

What is often referred to by entomologists as "natural" or "unexplained mortality" may be due to early stages of fungus growth not visible even under the hand lens. If conditions are such that the larvae dry completely too soon after death, the fungus development will be stopped before it became visible and thus pass for "unexplained mortality."


Fig. 203. Red Aschersonia, *A. aleyrodis*, of white-fly larvae, *Dialeurodes citri*. *A*, white-fly larva, showing development of the fungus; *B*, later development, with a fringe of hyphae from the margins; *C*, fungus pustule formed over the dead body of the larva. × 15. (After Webber, 1897.)

Red Aschersonia first appeared in 1892. Webber, who followed its beginnings with extensive observations in certain orchards at Panasoffkee, Florida, which had previously been severely injured by the white fly, reported (1897) a striking recovery of these same trees with the spread of this fungus. For some years the white flies and the accompanying sooty mold had been so bad as to require the washing of all fruits. With the visible spread of the fungus, the population of white flies was so much reduced in three years (by 1895) that no fruits had to be washed.

It was later shown (Fawcett, 1907, 1908) that this fungus could be grown readily in pure cultures on sweet potato strips. Following this, a method was perfected (Berger, 1910, 1921) by which large quantities of this fungus and the yellow Aschersonia were grown on sterilized sweet potato slices in pint bottles for use in artificial distribution.

For commercial use the cultures as described by Watson (1915) are made on sterilized strips of sweet potatoes 3 or 4 inches long and one-half inch in cross section standing in one-half inch of water in wide-mouthed pint or half-pint bottles. Spores from clean pustules are streaked on these strips with a needle. Good growth appears in about 7 days and red spores in 20 to 30 days, and the culture is mature enough to use in about 10 days more. A culture

is shaken in water, which is then filtered through a cheesecloth. It is recommended that application as a spray in Florida be made in June or July when the weather is rainy or moist. The cultures may be kept in storage a long time. At the Florida Agricultural Experiment Station these cultures have for many years been grown at cost for growers (Berger, 1932).[1] It is recommended that one pint of culture be used for each acre.

### YELLOW ASCHERSONIA

Yellow Aschersonia, *Aschersonia goldiana* Sacc. and Ellis.—This Aschersonia was formerly identified in Florida as *A. flavocitrina* P. Henn., but, according to Petch (1921*a*), is *A. goldiana.* It is reported on species of white flies in Florida, Cuba, Puerto Rico, Jamaica, Costa Rica, and Panama, and on an unidentified insect in Venezuela. The yellow Aschersonia appears to attack the cloudy-winged white fly more often than the citrus white fly, and has been found also on the woolly white fly. As developed in pure cultures on sweet potato slices, this fungus and the spores have been used in Florida for infecting the larvae of the cloudy-winged white fly.

It has pale yellow to whitish, circular, flattened pulvinate, stromatic pustules 2 to 5 mm. in diameter on the leaves (fig. 202). The spore cavities appear to be less sunken than in *Aschersonia aleyrodis* and the spores are longer, about 12 to 15$\mu$ long and 2 to 3$\mu$ broad (Fawcett, 1908).[2]

### WEBBER'S BROWN FUNGUS

*Aegerita webberi* Faw.—This fungus, the vegetative form of which was first discovered by Webber (1897) and the spore stage by Fawcett (1910), is an important parasite of the principal white flies in Florida. It has also been found in the West Indies, Ceylon, India, and New Zealand. It was studied by Petch (1926*b*). It is reported on larvae of at least three different species of white flies—citrus white fly, cloudy-winged white fly, and woolly white fly in Florida,—and on citrus black fly in Cuba.

In its sterile form it consists of a chocolate-brown compact stroma (fig. 204). From the margins of this stroma, there extend colorless, thick-walled hyphae. Later in the development of the fungus (usually in the summer or fall) the hyphae at the margins of the stroma grow out long and colorless, extending not only over the under surface of the leaf but also around the edges and upon the upper surface. Sometimes the fungus extends down the petiole and along the stem to the next leaf, infecting every larva in its path. Sometimes the hyphae become very abundant and form silky, grayish-brown strands that almost completely cover the leaf surface.

This fungus is, under some conditions, one of the most efficient parasites of white-fly larvae. When once detached from the leaf, the sporodochia blow about on smooth surfaces at the slightest motion of the air, but on alighting upon another leaf or rough surface they tend to hold fast to it. The inflated cells of the sporodoch-

[1] They are still being used for control of white fly in Florida, according to a letter from J. R. Watson, 1942.

[2] *Sirosperma Hypocrellae* Syd., a superparasite on *Aschersonia goldiana*, was identified by Petch on pustules from Los Tegues, Venezuela. It forms a thin stroma of hyphae which surrounds the parasitized pustule with a black circular patch.

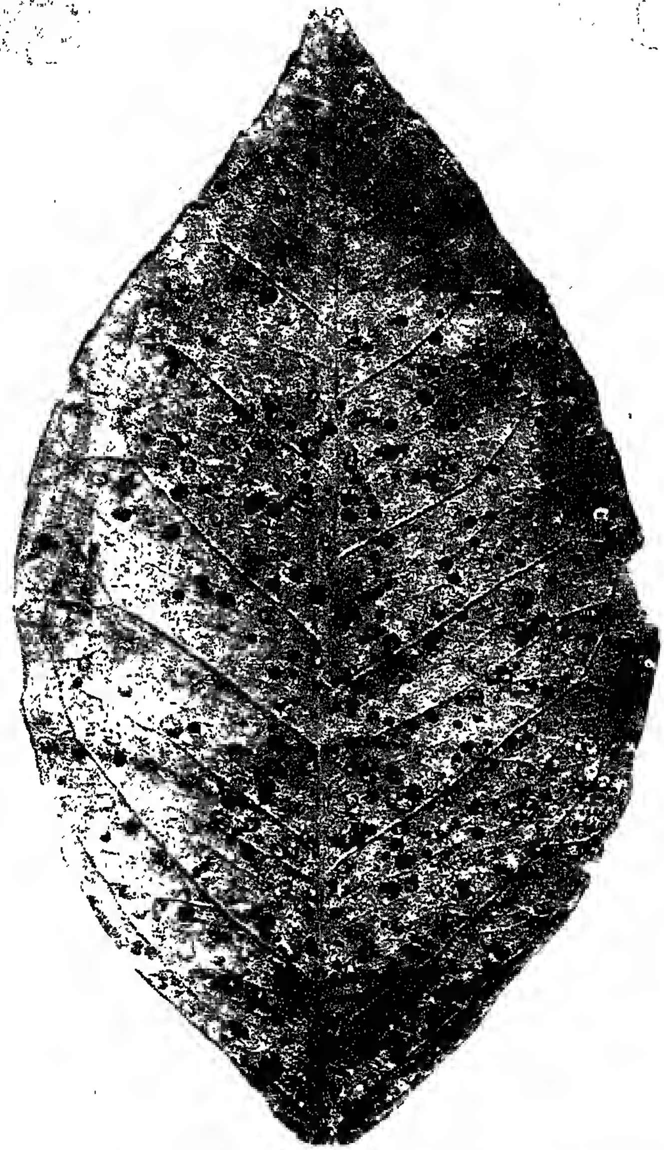

Fig. 204. Webber's brown fungus, *Aegerita webberi*, on larvae of the citrus white fly, *Dialeurodes citri*. A few lighter colored pustules of the red Aschersonia, *A. aleyrodis*, on the right. About natural size.

ium make it light so that it blows about easily. It seems probable that the appendages may also serve to hold the sporodochia to bodies of large insects that drag them from one part of the tree to another or from tree to tree (Fawcett, 1910).[1]

The discovery of this fungus and the first observation of its rapid spread are of special interest. In March, 1896, Webber (1897) first found it in part of a five-acre orchard in Manatee, Florida. He reports that millions of live larvae could be found at that time in trees where the fungus had not spread. No trace of the fungus was to be seen in adjoining orchards. By December the fungus had spread with surprising rapidity, and it was difficult to find a living specimen of white fly in the orchard. The black, sooty mold which had formed a covering on leaves and fruits had been washed off by rains and nearly all fruits were clean. New fall growth was also nearly free from larvae. The adjoining orchards, however, were abundantly infected with live larvae and the leaves and fruit were covered with black mold growing in the honeydew. By the following year the fungus had spread over a radius of about two miles, reducing the larvae as it spread. Webber also found larvae of all stages infected.

Experiments with the sporodochia of the brown fungus (Fawcett, 1910) drawn with a camel's-hair brush over white-fly larvae in August showed effects of the fungus in nine days, and branching hyphae were seen within the bodies of the larvae. In the same manner as described by Webber, the initial stage of the brown stroma burst through the edge of the larvae in sixteen days. The typical brown pustules (fig. 204) were produced in a few weeks and the sporodochia in two or three months. Healthy noninoculated larvae used as checks remained uninjured.

No successful method of growing this fungus in pure cultures in large quantities has yet been developed, but its distribution has been effected in various ways, such as (1) pinning pustule-bearing leaves to leaves containing live white-fly larvae, (2) grinding up the pustules and stirring them in water to be sprayed on the trees, or (3) planting young fungus-bearing trees so that the leaves intermingle. If the sporodochia are abundantly developed on leaves, stirring the leaves in water to get the sporodochia off, and then spraying the water on trees infected with white fly, spreads the fungus readily. Of the effectiveness of this fungus under certain conditions, Morrill and Back (1912) state: "The brown fungus has been so effective in controlling white fly in certain low-lying hammock groves in Lee County, Florida, that it must be conceded this fungus has made artificial remedial measures unnecessary. Such groves, however, are an exception to the rule at the present time."

## FUNGI USUALLY OF MINOR IMPORTANCE ON ALEYRODIDS

White-fringe fungus, *Fusarium aleyrodis* Petch (1921*c*).—This was at first erroneously called *Microcera* sp. (Fawcett, 1908). The white-fringe fungus is found commonly on larvae of the white fly in Florida. It is seen on both

[1] On the brown fungus has been found a hypoparasite, *Sirosphaera chlorostoma* Petch (1926*b*), which causes the pustules to appear green. The pycnidial bodies often form a ring around the edge of the *Aegerita* pustule.

citrus white fly and cloudy-winged white fly, but has been reported also on scale insects. It is believed by some to be of major importance.

This fungus presents a fringe of delicate white hyphae growing outward from the edges of the larvae. These hyphae at first bear one-, two-, or three-celled conidia, which are oval to fusiform in shape. Afterwards, there are formed on the edge of the larvae pinkish spore masses which are made up of a compact mass of lunate spores.

It is usually considered to be less effective in its parasitism than the red or the yellow *Aschersonia*, or the brown fungus. It is most prevalent in moist warm weather. The white-fringe fungus was readily grown in pure culture and shown experimentally to parasitize larvae of *Dialeurodes citri.* Watson (1913, 1914*a*) was able, even when fungus was already present, to double the mortality in certain experiments by spraying on spores at Gainesville, Florida. In certain culture tests in which mercuric chloride was used to disinfect the surfaces, Watson (1913) found that 98 per cent of the larvae showing a "natural mortality" had the fungus in them. A majority of these showed no fungus to the unaided eye. He also found this fungus on adult white flies and isolated the fungus from them. Among the fungus filaments of dead adult flies were many eggs, apparently parasitized and shriveled.

Cinnamon fungus, *Verticillium cinnamomeum* Petch.—This fungus, first seen in Florida in 1905 and studied in pure cultures by Fawcett (1908), was shown to parasitize white-fly larvae. It is reported on white flies in Alabama, Mississippi, and Florida, and on scale insects (see p. 647).

In general appearance the pustules produced by the compact hyphae of this fungus on white-fly larvae resemble those produced by Webber's brown fungus, but on close examination they are seen to be different. The cinnamon-colored pustules are powdery on the surface, and under the hand lens appear brushlike, bristling with hyphae. When fruiting, the upright spore-bearing stalks have either simple or compound whorls of branches.

Adult white-fly fungus.—A species of *Sporotrichum* producing a copious growth of white mycelium was isolated in September, 1908, from the adult winged stage of white flies (Fawcett, 1908; Berger, 1909); it was thought from observation to have caused the death of a large number of them. The species was not identified, and no subsequent work on this fungus is known. It is suspected of being similar to *Beauveria globulifera.* The finding of the white-fringe fungus, *Fusarium aleyrodis,* on adult white flies has previously been mentioned.

Other Aschersonias or Hypocrellas on aleyrodids.—*Aschersonia papillata* Petch (1925*d*), with yellow or dark honey-colored pustules, was reported on a black aleyrodid on citrus in Ceylon. *Aschersonia columnifera* Petch (1921*a*), with pale yellow pustules, and *A. brunnea* Petch (1922), with dark brown pustules, though not reported on citrus, are found on aleyrodids on *Ilex dahoon* and on *I. cassine* in the citrus districts of Florida. *Aschersonia aristata* Ell was collected by H. J. Webber on *Lecanium* sp. on red bay in Florida in 1895.

*Hypocrella turbinata,* described under "Fungi of Scale Insects," is reported on the citrus black fly in Puerto Rico; *Hypocrella Raciborskii,* on *Aleurodes* sp. on citrus in India; *Hypocrella phyllogena* (Mont.) Petch, on the citrus white fly in Puerto

Rico and on aleyrodids on *Ilex cassine* in Florida; and *Hypocrella epiphylla* (Mass.) Sacc., on citrus black fly in the Canal Zone. Others are *Rhinotrichum album* Petch, reported also on *Aleurodes* in Ceylon, and *Cladosporium* sp., probably saprophytic on citrus white fly. See *H. turbinata*, *H. epiphylla*, and other *Hypocrella* on scale insects, p. 644.

## FUNGI OF SCALE INSECTS

Under certain conditions of temperature, humidity, and probably light and other factors, scale insects[1] may be attacked by a number of different fungi. If conditions are unusually favorable in some low-lying localities, as in Florida, most of the scale-insect populations appear to remain at a low density level and therefore do little damage to the trees or fruit. In Brazil generally, as in Florida, a copious entomogenous fungus flora occurs, effecting a large measure of natural control of scale insects (Bitancourt and Fawcett, 1937). In the state of Pernambuco, however, the summer rainfall is small and irrigation must be practiced. As in California, the summers are dry and Pernambuco, therefore obtains little benefit from the fungus parasites. In the higher, drier localities of Florida, however, or in regions exposed to wind, these insects become very abundant during the dry season of winter and spring unless the control by natural enemies is supplemented by insecticides.

In Florida, evidence has been reported which shows that not all the increase of scale insects after bordeaux spraying there is due, as previously indicated (Fawcett, 1913; Hill, Yothers, and Miller, 1934), to the killing off of the fungi; it is found that lime and other materials not considered as fungicides also cause large increases in purple-scale insects and spider mites.[2] Several authors have concluded from spraying experiments that these increases cannot be attributed entirely to the prevention of fungus infection, but that they are also due to the effect of residues (Osburn and Spencer, 1938; Thompson, 1935, 1938, 1942; Camp, 1943). The diversity of opinion on this subject is well stated by Holloway and Young (1943): "Some believe that elimination of the fungi is the major factor; others, that the inert granular residue contained in the spray is the most important factor; and still others, that the increase is the result of the combination of the two factors." These authors then present results of experiments in spraying, in Florida, trees on which purple scale occurred, which led them to conclude that "the most important factor causing abnormal purple scale increase following use of fungicidal sprays is the inert granular residue content of the spray."

In writing of conditions in California, where no known entomogenous fungi of purple scale occur, R. S. Woglum[3] states: "I know of no references to scale build-up, and my own experience is that Bordeaux or sulfur coating does not influence scale here in California, or if it does have any influence, it is so small as to be of no commercial value."

[1] For scientific names of insects mentioned by their English names, see table 49, p. 657.

[2] Dusts such as lime and sprays containing zinc sulfate and copper sulfate (Holloway, Henderson, and McBurnie, 1942) also result in increases in red spider in California, but there appears to be no evidence that purple scale in California is increased by lime or by bordeaux.

[3] Letter of December 18, 1942, to the author.

In interpreting the results of these experiments with residue-producing sprays, certain factors should be taken into account: (1) the possible effect of the nonfungicidal and fungicidal materials on the tree itself; (2) the possible effect of the material on the nutrition and development of the insect in making it more resistant or susceptible to infection by the fungi; and (3) the possible effect of weather or other conditions soon after the application of the materials on the fungus and on the insects.

It would appear that there is a complex of possible, fluctuating factors that needs to be resolved by experiments utilizing controlled conditions for the insects, for the fungi themselves, and for the fungus-insect relationship before the parts played, respectively, by the deposits or residues from applied materials, by nutrition of the tree and thereby the nutrition of the insects, and by the parasitic organisms, can be definitely known.

## THE RED-HEADED SCALE FUNGI

Two species of *Sphaerostilbe* are found on scale insects of citrus in North and South America, namely, *S. aurantiicola* (Berk. and Br.) Petch and *S. flammea* Tul., and one in the Orient, *S. coccidophthora* (Zimm.) Petch. The first two were often called *S. coccophila* in earlier publications.

*Sphaerostilbe aurantiicola* (Berk. and Br.) Petch.—This fungus has been reported on a large number of scale insects on citrus and other host plants. Those on citrus in North America, principally in Florida and the West Indies, are California red scale, Putnam's scale, ivy scale, snow scale, Florida red scale, Spanish red scale, green scale, thread scale, purple scale, Glover's scale, chaff scale, citrus mealybug, black scale, rufous scale, and San Jose scale. A previous report of the occurrence of this fungus on the two common species of white-fly larvae was probably a mistake. It is also found on scale insects in Brazil, Ceylon, India, Madagascar, New Guinea, Japan, Formosa, and Italy. It is reported on Florida red scale and California red scale in Argentina.

The imperfect pustules are clavate or flattened pulvinate in form, orange-red to blood red, and about 2 mm. high and 0.4 to 0.6 mm. in diameter. Its perfect pustules (perithecia) are small, about 0.25 mm. in diameter, subglobose, smooth, orange-red to blood red. It appears to be one of the most prevalent fungi on scale insects, especially in Florida and the West Indies. Its effect in Florida is reported to be greater on the purple scale than on the red scale, the opposite of that of the pink fungus, *Nectria diploa*, which is more effective on the red scale.

*Sphaerostilbe flammea* Tul. (*Nectria aglaeothele* B. and C.).—This fungus on citrus has been reported on snow scale in Panama and Florida and on various coccidae of many hosts besides citrus; also on an unidentified scale insect of citrus in Australia and from insects of other hosts in many other parts of the world, where it has been described under many different names (Petch, 1921c).

The red pustules or heads of the imperfect form of this fungus are conical or clavate, either stalked or sessile. They may attain a height of 2.5 mm., but usually

are much smaller. The perfect forms are crowded together on a stroma which often hides the scale insect. When mature, they are bright orange-red.

*Sphaerostilbe coccidophthora* (Zimm.) Petch.—This fungus, first described as *Nectria coccidophthora* (Zimm.), was reported on black parlatoria scale on citrus and *Lepidosaphes* sp. on coffee in Java. It was also found on a tea and bamboo insect in Ceylon.

The heads of the imperfect form are orange-red or scarlet, paler toward the base, usually stalked, clavate, expanding into an ovoid top. They are usually 0.8 mm. high, but may reach a height of 1.4 mm. The subglobose heads of the perfect forms are scattered or clustered. They are only 0.2 to 0.3 mm. in diameter; are orange-red, becoming blood red; and are covered with minute yellowish-red granules. This species has not been recorded in North America.

Fig. 205. The pink fungus, *Nectria diploa*, on scale insects on a citrus twig. Twice natural size.

## NECTRIA FUNGI

Four species of *Nectria* are found on scale insects of citrus.

*Nectria diploa* (B. and C.).—This fungus, called in Florida the "pink fungus," forms pustules somewhat similar in general appearance to those of the red-headed fungus. Its imperfect stage (fig. 205) was known as *Microcera fujikuroi* Miy. and Sa. (*Pseudomicrocera Henningsii* (Kood) Petch is also a synonym.) It appears to be effective, especially on Florida red scale, but has been found also on purple scale, long scale, black scale, thread scale, and the California red scale in Florida. It also occurs on scale insects in Australia and Formosa. It is reported on California red scale in Southern Rhodesia, and was found by the author on Florida red scale in the states of São Paulo and Bahia in Brazil. The countries in which it is found on various plant hosts, citrus and others, include Paraguay, Brazil, Cuba, Florida, Puerto Rico, Mauritius, Ceylon, India, Java, Burma, the Philippines, Formosa, Australia, and West Africa.

The stroma are light rose color, 0.7 to 1.0 mm. broad, and develop at the base and over a part of the surface of the scale. The pustules or heads of the imperfect form (fig. 205) are 1 to 3 to a scale, rose-colored or pink and 0.5 mm. high. The heads of the imperfect form are 0.4 mm. in diameter, bright red, and covered with warts.

Watson (1915) found it an efficient parasite on Florida red scale and was able to spread it experimentally. In April he placed fungus-and-insect-bearing leaves in water and dipped branches of small trees in the resulting spore suspension. It spread from July to November, killed every scale on the leaves, and spread out one-half inch or more in all directions on the leaf surface. It occurs also on purple scale, but with less effect than on red—just the opposite of what the red-headed fungus, *Sphaerostilbe aurantiicola,* does.

*Nectria barbata* Petch (1921*c*).—This fungus is reported on *Lepidosaphes* sp. on citrus in Ceylon. The perithecial pustules are scattered over the scales with slight basal wefts of hyphae. They are conoid or subglobose, about 0.2 mm. in diameter and 0.3 mm. high, yellow-brown or dark amber in color.

*Nectria vilis* (Syd.) Petch (1925*b*).—This fungus has an imperfect form known as *Tubercularia coccicola* Stev. and is the same as *Nectria tuberculariae* Petch. The imperfect form is reported on snow scale and purple scale in Puerto Rico and an unidentified scale in Brazil. The stromatic pustules may be as much as 0.2 mm. in diameter, white to yellowish white, sometimes light pink. The perithecia are buried in the conidial stroma, dark red-brown or yellow-brown, and may measure as much as 0.12 mm. in diameter.

## THE WHITE-HEADED SCALE FUNGI

Three species of *Podonectria* are found on citrus, the first two of which have white heads, the third, purplish brown heads.

*Podonectria coccicola* (E. and E. Petch).—This fungus has been found on purple scale, Glover's scale, and chaff scale in Florida. It was one of the first entomogenous fungi noted in Florida (Hubbard, 1885). Hubbard referred to it as the bark fungus. By Watson and Berger (1937) and Berger (1942) it is thought probably to have been the main factor in reducing the destructiveness of Glover's scale after that scale had been introduced into Florida at Mandarin and St. Augustine in the eighteen-thirties. At first, trees were killed back annually by severe infestations of long scale, which could not be controlled by any known means; but after some years the scale was reduced by some unknown cause and the trees recovered; the improvement, it is now believed, was due in part at least to this fungus, later reported by Hubbard. It is also reported in the West Indies, Ceylon, Java, Japan, and South America: in Japan on the purple scale, and in Japan and Argentina on Glover's scale; in Java, Queensland, and Brazil on unidentified scales. The fungus *Schleroderris gigaspora* Mass. on purple scale reported in Barbados is probably *Podonectria coccicola,* according to Petch (1921c).

The imperfect form, *Tetracrium coccicolum* H., consists of small, white, subconical heads mounted on cylindrical or ovoid brown bases, forming pustules 0.5 mm. high and 0.4 mm. in diameter. The perfect stage possesses perithecial pustules, ovoid or subglobose, brown to dark brown, 0.6 mm. high and 0.4 mm. in diameter (figs. 206 and 207).

*Podonectria aurantii* (V. Höh) Petch (*Ophionectria tetraspora* Miy. and Sa.).—This fungus is similar in appearance to the preceding, and is found in Brazil on a citrus scale and in Formosa on the black parlatoria scale.

Imperfect heads, rounded, somewhat depressed, globose, dark gray, about 0.5 mm. in diameter and 0.4 mm. high. Perfect perithecial heads on a stroma, clustered, white, woolly, globose, clothed with thick-walled, woolly, fine hairs, often united into fascicles.

Fig. 206. Perfect stage of the white-headed scale fungus, *Ophionectria coccicola,* on purple scale on citrus twig. Twice natural size.

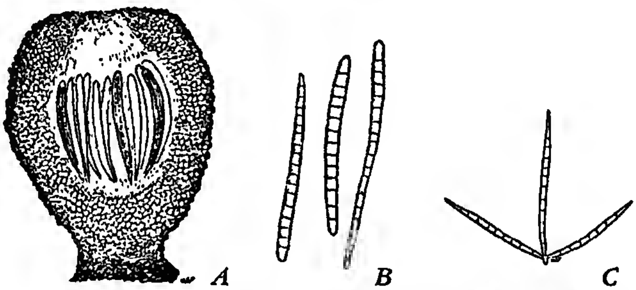


Fig. 207. Pustule and spores of the white-headed fungus, *Ophionectria coccicola. A,* cross section of a perfect pustule, showing asci or spore cases, × 80; *B,* ascospores, × 400; *C,* conidial spore, × 130.

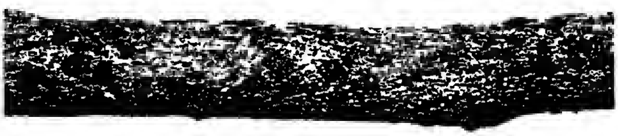

Fig. 208. The black fungus, *Myriangium duriaei,* on scale insects on citrus bark. The flat black patches are the pustules of the fungus. About natural size.

*Podonectria echinata* Petch.—This species occurs in Ceylon on *Lepidosaphes* sp. The imperfect heads are similar to those of *Podonectria aurantii* described in the preceding section.

The stromatic pustules are purple-brown, not extending far beyond the scale. The perithecial heads are globose, about 0.15 mm. in diameter, pale yellow, covered with projecting fascicles of hyphae measuring as much as 0.2 mm. in length.

LISEA FUNGUS

*Lisea parlatoria* Zimm.—This has been noted on the black parlatoria scale on citrus leaves in Java (Petch, 1921*c*).

It has dark, globose, perithecial heads 0.2 to 0.25 mm. high and 0.15 to 0.18 mm. in diameter, crowded together. The walls of the perithecia are dark violet to black by transmitted light.

THE BLACK FUNGI OF SCALE INSECTS

Three species of *Myriangium* constitute the black fungus on citrus scale insects: *Myriangium duriaei* Mont. and Berk. and *M. floridanum* Hoehn. in North America (Miller, 1940), and *M. montagnei* Berk. in the Orient.

These three fungi form black carbonaceous crusts on the surface of scale-infested twigs, leaves, and fruit. The pustules or stroma of these fungi vary in size to as much as 5 mm. in diameter, are black or purple-black and either shiny or dull (fig. 208).

*Myriangium duriaei.*—This fungus, according to Miller (1940), is synonymous with *M. Curtisii* and appears to be widely distributed on many kinds of scale insects from temperate climates to the tropics. In Florida and the West Indies it occurs, on citrus, on the purple, Glover's, San Jose, and chaff scale; in Texas, on various scales, including the California red scale; in Argentina, on *Lepidosaphes* sp.; in Ceylon and the Philippines, on California red scale; and in São Paulo, Brazil, on an unidentified insect. This fungus, as designated by Petch, also occurs generally in the tropics and extends into the temperate zone on insects of many hosts. It is reported that on one occasion of its use in Florida all the chaff scale, purple scale, and Glover's scale on citrus trees were killed in one and one-half years and the trees remained free for at least four years (Watson and Berger, 1937).

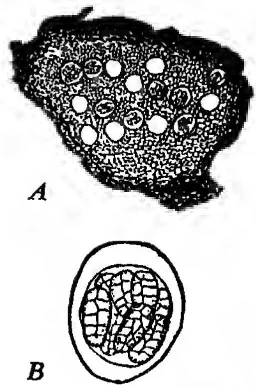

Fig. 209. Black fungus, *Myriangium duriaei*. *A*, cross section of perfect stage, × 70; *B*, ascus with spores, × 350.

The stroma is black with pale interior, fleshy to gelatinous when wet, flat to convex, orbicular, plicate-radiate; it is 1.5 to 5 mm. in diameter, has few to many apothecia arising as erect processes with depressed center; and is 0.5 to 1.5 mm. in diameter and 0.5 to 1 mm. high (Petch, 1924) (figs. 208 and 209).

*Myriangium floridanum* Hoehn.—This species occurs on the snow scale and purple scale in Florida.

Stroma of this species are very thin, flat; indefinitely effused, following the contours of the bark; black externally and of light straw color inside; apothecia are isolated or crowded, sessile, elevations pulvinate, hemispheric to truncate, 0.1 to 0.3 mm. high and 0.3 to 0.6 mm. in diameter, surface black, pulvinate, with no free margin.

*Myriangium montagnei* Berk.—This species occurs in New Zealand, Tasmania, and Australia. It has been reported on "mussel scale" (purple scale) in the eastern Transvaal.

Stroma as much as 5 mm. in diameter, pulvinate or flattened pulvinate, tuberculate at first, without free margin, dark brown, appearing tomentose, becoming black and more or less shining, internally pale brown, substance cheesy, not friable; apothecia are mostly sessile, discoid with a stout black margin and a sunken black or brown disk as much as 1 mm. in diameter or concave to as much as 2.5 mm. in diameter. In general, the apothecia are sessile.

## HYPOCRELLA FUNGI

The species of *Hypocrella* on scale insects have their imperfect stages in *Aschersonia* and are therefore related to the *Aschersonia* previously mentioned on white-fly larvae. Two of these *Hypocrella* occur on aleyrodids but are also found on scale insects.

*Hypocrella turbinata* (Berk.) Petch (*Aschersonia turbinata* Berk.).—This species, probably the same as *Aschersonia pittieri* P. Henn., is known in Florida as the turbinate *Aschersonia*. Besides being reported on the citrus black fly in Puerto Rico, it has been found on the wax scale in Florida, Louisiana, and the Canal Zone; on brown scale in Louisiana; on purple scale in Florida, Louisiana, and Puerto Rico; on soft brown scale in Costa Rica; and on an unidentified insect on citrus in Florida and on the Isle of Pines. It forms white to pink stromatic pustules, becoming dark when old, about 1.5 mm. broad and 1 mm. high, with a truncate upper surface often concave.

*Hypocrella javanica* (Penz. and Sacc.).—This Javanese *Hypocrella* is, according to Petch (1921*a*), the perfect stage of *Aschersonia coffeae* P. Henn., *P. pediculoides* P. Henn., *A. eugeniae* Kood, and *A. suzukii* Miy. and Sa. It occurs on various scale insects and hosts, but is found on California red scale, on *Citrus nobilis* in Japan, and on other hosts in Ceylon and India. The *Aschersonia* stage varies from cream to cinnamon, orange, or red brown, is hemispherical and 1 to 4 mm. in diameter. The perfect stage is white, hemispherical to two-thirds globose to as much as 5 mm. in diameter.

*Hypocrella reinekiana* P. Henn.—This dark globose *Hypocrella* has imperfect stages, according to Petch (1921*a*), in *Aschersonia marginata* E. and E., *A. sclerotioides* P. Henn., and *A. pisiformis* Pat. As *Hypocrella* it is reported in Ceylon and Formosa on *Lecanium* and *Parlatoria* scales. As *Aschersonia marginata* it is reported in Madagascar and Queensland, and as *A. sclerotioides* in the Philippines. The pustules are hemispherical or two-thirds globose and may measure as much as 4 mm. in diameter, at first pale or buff, becoming slate-colored and finally black.

*Hypocrella epiphylla* (Mass.) Sacc.—The *Aschersonia* stage is *Aschersonia cubensis* Beck. and Cust. It occurs on citrus in Florida on the wax scale, brown scale, purple scale, and hemispherical scale. On other host plants, it is found in Ceylon, Trinidad, St. Vincent, Cuba, Brazil, and Peru. As *Aschersonia cubensis* it has been reported on citrus black fly in the Canal Zone.

Perfect-stage pustules are subhemispherical or two-thirds globose, buff or reddish brown, and may be as much as 2 mm. in diameter. *Aschersonia*-stage pustules are white or buff or reddish brown, 1 to 4 mm. in diameter. The *Aschersonia* stage of this fungus was grown in pure culture by Berger in 1920 in Florida.

CEPHALOSPORIUM FUNGUS

*Cephalosporium lecanii* Zimm.—This fungus is reported in Florida (Watson and Berger, 1937) as an effective parasite on pyriform scale. On citrus there, it also occurs on brown scale and hemispherical scale; also on certain scale insects of mango, magnolia, palm, and a pine. In Florida and the West Indies, it occurs on the green scale and the cottony cushion scale; in Ceylon, on the green scale; and in Puerto Rico, on wax scale, brown scale, black scale, hemispherical scale, and nigra scale. It has been reported in British Guiana, Brazil, and New Zealand. In Argentina it is reported on the scale insects of olive and other plants.

Around and over the scale insects a white or pale yellow powdery bloom appears, caused by the numerous minute heads or clusters of spores. In Brazil this fungus[1] is reported as an effective parasite of green scale on coffee plants: it destroys all the internal parts, including the eggs.

Two methods of spreading the fungus are used in the State of São Paulo: (1) heavily shaded branches affected with the fungus are placed in coffee plants infested with the scale; or (2) the infested plants are sprayed with a heavy suspension of fungus spores.

Other species of *Cephalosporium* reported on citrus insects are *Cephalosporium (Acrostalagmus) coccidicolum* Guiguen on a *Pulvinaria* sp. in Argentina, *Cephalosporium longisporum* Petch on a cottony cushion scale in Ceylon, and *C. coccorum* Petch on brown scale in Italy.

"ISARIA" FUNGUS OF BLACK SCALE

In moist seasons in California near the coast, a white, delicate, powdery fungus frequently appears underneath and on the edges of black-scale larvae. In Santa Barbara County, when natural conditions are favorable, it appears to kill the black scale, more or less. This fungus has been known as "Isaria," though no true Isaria stage has been noted. It may be similar to *Beauvaria globuliferum.* It sometimes appears to attack the young under the scale covering. Isaria does not appear to thrive more than a few miles from the coast, and even there it appears to be an uncertain and variable factor.

In experiments by Quayle and Tylor (1915) with cultures of Isaria in a moist chamber in the laboratory or in the field, a fair proportion of the scales were killed, but when attempts were made to disseminate the fungus artificially under natural conditions in the field the results were wholly negative.

An *Isaria* sp. is also reported on black scale from North Carolina and Virginia (Charles, 1941).

CLADOBOTRYUM FUNGUS

*Cladobotryum heterocladum* (Penz.) Petch (1932) as occurring on the brown scale in Italy was described by Penzig as *Verticillium heterocladum.* The *Cladobotryum* fungus differs from the Florida fungus. Its branches

[1] According to Viegas (1939), the name of the fungus should be *Verticillium lecanii* (Zimm.) Viegas.

as checks, another nonparasitic species of the *Aspergillus flavus-oryzae* group with similar growing habits. The insects remained alive in the check cultures although they were in constant contact with the same amount of fungus mycelium and spores as were those in contact with the parasitic species of *Aspergillus*.

*Aspergillus parasiticus* Speare was shown by Speare (1912) to be highly parasitic on the sugar-cane mealybugs in Hawaii, killing young, freshly hatched insects even more readily than older ones. A fungus not distinguishable from *Aspergillus parasiticus* was reported by Johnston (1915) in Puerto Rico on a sugar-cane mealybug.

### ENTOMOPHTHORA FUNGUS AND OTHER FUNGI

*Entomophthora fumosa* Speare.—This fungus is considered (Speare, 1922) to be one of the chief factors, especially during periods of summer rains, in the natural control of the citrus mealybug in Florida. The disease is recognized in its early stage by a milky-white liquid which emerges from the crushed insect bodies. Spherical thin-walled "hyphal bodies" are seen in the liquid under the microscope.

The mealybugs are "enveloped in a dark slate-gray covering," giving the name "fumosa" (smoky). Sometimes they are jet black and semiglistening. Very thick-walled, smoky-colored resting spores are formed internally. These probably tide the fungus over unfavorable periods.

Other fungi on mealybugs of citrus are *Empusa fresenii* and *E. lecanii*, reported below under the "Aphid Fungi," and *Sphaerostilbe auranticola*, reported above under "Fungi of Scale Insects."

## APHID FUNGI

### EMPUSA SPECIES

Species of *Empusa* are among those which are highly parasitic on various insects.[1] One of the well-known species is *Empusa muscae* Cohn, the cause of the so-called "frosted flies." Another species, *E. chromaphides* Burger and Swain (1918), was reported on about 88 per cent of the walnut aphis during one season. At least three species are reported on citrus insects: *Empusa fresenii* Now., *E. sphaerosperma* (Fres.) Thax., and *E. lecanii* Zimm., the last one attacking a noncitrus aphid, a citrus scale insect, and a mealybug.

*Empusa fresenii* Now.—This fungus is reported to be the chief factor, under certain conditions, in the control of the spirea aphid on citrus in Florida. The fungus also occurs on the black citrus aphid, on aphids on Tephrosia in West Africa, and on the sugar-cane aphid in the Philippines. Insects killed by the fungus are attached to the leaf solely by their proboscis and appear as if standing on their heads. The abdomen and thorax become coated with tan-colored to light smoky brown glistening spores. The interior body material is almost replaced by fungus. Affected insects at first show a yellowish color over thorax and fore abdomen. The proboscis turns dark. After death, the insects change from yellow through light brown to a ripe olive

[1] For scientific names of insects mentioned see table 49, p. 657.

color. The production of spores gives a tan to smoky color to the body, which glistens in the sunlight. Parasitism is favored by warm, humid weather. A colony of aphids is destroyed in a few days after the fungus attack. The spores are not wind-borne, but depend for infection on the migration of the insects; in Florida, migration was found to extend as much as 500 yards. Epidemics start with the beginning of this migrating period (Gilbert and Kuntz, 1926; Kuntz, 1926, 1928; Tisdale, 1929, 1930). Overwintering zygospores have been found.

*Empusa sphaerosperma* (Fres.) Thax.—This *Empusa* has been reported on the potato leaf hopper, an insect sometimes attacking citrus. It is also reported on many noncitrus insects, as, for example, the clover-leaf weevil and alfalfa weevil in California, and the potato orchid in Florida. It has been reported by Vasseleiv (1914) to have caused the death of 60 to 70 per cent of a population of grain beetles. It also occurs on fire worm (Sawyer, 1933) and on *Plutella* (Ullyett and Schonken, 1940).

The fungus appears white, varying to bright pea green externally. In cages, the surface of larvae may become covered with a yellowish, translucent coating, with globules of spores on hairs. Resting spores are hyaline, spherical, and very slightly yellowish.

*Empusa lecanii* Zimm.—This fungus, although reported on sugar-cane aphid in the Philippines, also occurs on two citrus insects, the citrus mealybug in Louisiana and the green scale in Ceylon, South India, and Java (Petch, 1926*c*).

The fungus on the green scale causes it to become first white, then grayish in color. In the white stage the body of the insect is filled with colorless cells. The gray stage is produced by the germinating of the spherical cells and their production of short hyphae. In the Philippines, experiments showed that the fungus killed 80 to 95 per cent of sugar-cane aphis in experimental cages.

Many other species of *Empusa* attack insects not common to citrus. See also *Acrostalagmus aphidum* and *Cladosporium aphidis*.

### FUNGI OF MITES

Speare and Yothers (1924) state that in Florida, annually since 1912, the citrus rust mite[1] has been observed to disappear as if by magic sometime after the beginning of the rainy season, which is usually late in June or early in July. By the middle of September it has been difficult to find a single mite present where they have been abundant before.

The dead mites had fungus filaments protruding from their bodies. Fungus hyphae were found inside mites that were sluggish in their movements. So far as is known, this fungus has not been identified, nor has its relation to the death of mites been determined by experimental tests.

Charles (1940) has described the fungus *Rhinotrichum depauperatum*, found on the avocado red mite in Florida, on *Piaropus crassipes* (Mart.)

[1] For scientific names of insects mentioned see table 49, p. 657.

Britton. This fungus consisted of an effuse, cobwebby, white to pale gray mycelium in which the mites were enmeshed. The mites were killed experimentally in eighteen hours when exposed to this fungus. Petch (1940) described a new species of *Empusa, E. acaricida,* which gives the undersurface and sides of the red-legged earth mite a yellowish-brown color, owing to the presence of a mass of hyphae bodies just below the cuticle. This identifies the infected mites, since normally they have jet black bodies. Petch (1944) also describes *Empusa acaridis* on a mite, *Pergamasus crassipes* L., in Norfolk, England. The question arises, May the citrus rust-mite fungus be something of this nature?

## MISCELLANEOUS FUNGI OF CITRUS INSECTS

### SPICARIA FUNGI

The genus *Spicaria* has been discussed by Petch (1925*c*).

*Spicaria javanica* Bally.—This fungus, on cottony cushion scale,[1] forms a delicate grayish-lavender powdery growth, similar to Botrytis, in Florida and Puerto Rico. It is also reported in Ceylon on a Ceroplastes, green scale, and cottony cushion scale, and on a caterpillar.

In Florida, Watson and Berger (1937) report that it is very effective when weather conditions are warm and moist, but does not keep insects completely in check without the vedalia. In Puerto Rico, Wolcott and Sein (1933) reported that this fungus so completely killed the cottony cushion scale on citrus in orchards well protected by hills and bamboo windbreaks that none was seen for at least seven years or during the time of observation. At other places, however, with less perfect windbreaks, it was not effective.

This fungus forms loose white masses covering the insect. The conidiophores are hyaline, branched above, with branches in whorls. Lateral branches are short, branching again and bearing 2 to 4 flask-shaped spores at their apices.

*Spicaria rileyi* (Farl.) Charles.—This fungus, formerly known as *Botrytis rileyi,* is found on the caterpillar of velvet bean, which is an important cover crop of citrus.

It is a pale greenish-blue fungus. The attacked caterpillar becomes flaccid and ceases feeding in 3 days. The anterior part of the body is raised at an angle of 45° as the caterpillar dies. Only a day later, the spores mature in great numbers. It attacks all insects alike. Resistance seems to be lowered by relatively cool weather. Watson (1916) reports epidemics in September or October in Florida, where only a fraction of one per cent escaped at the end of a week. Wolcott and Martorell (1940) report an epidemic in which the fungus was very effective in killing all of the last instars on velvet-bean plants in Puerto Rico.

*Spicaria heliothis* Charles.—This species is reported on the corn earworm that is sometimes a pest of citrus, especially in South Africa.

According to Charles (1938), this fungus is often not evident externally, but sometimes emerges and forms a cobwebby mass. Pupae may frequently be found

[1] For scientific names of insects mentioned by English names see table 49, p. 657.

encased in a smooth, white, mycelial sheath. The bodies of the insects contain a mass of tightly packed mycelia which causes nearly complete obliteration of all organs except the alimentary canal.

SOROSPORELLA FUNGUS ON CUTWORM

*Sorosporella uvella* (Krass.) Gd.—This fungus is reported on the corn earworm, an insect sometimes found on citrus. It completes its entire development in the body of its host, producing no growth externally. As Speare points out: "While the majority of mycologists are likely to overlook these fungi through lack of familiarity with insects and their habits, it is equally

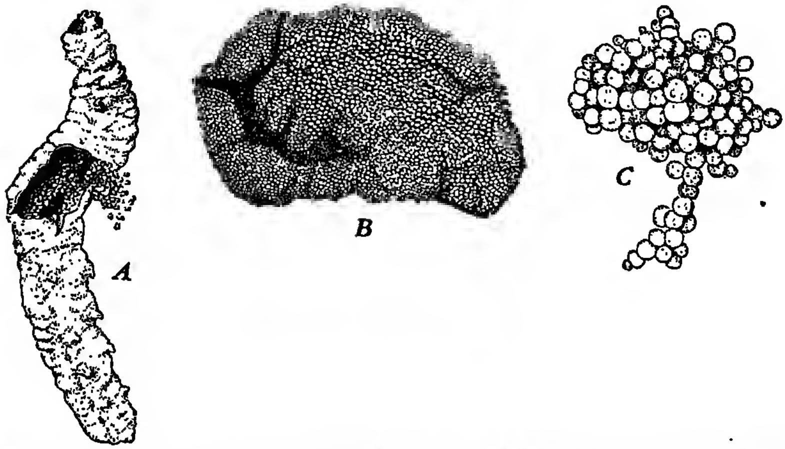


Fig. 210. *Sorosporella uvella,* an internal parasitic fungus on cutworm. *A,* larva filled with spore masses, × 1.2; *B,* spore masses, × 120; *C,* portion of a spore mass, × 253. (After Speare, 1917.)

true that their ignorance of mycology usually led entomologists to give them at best scant attention even when their presence is evident."

According to Speare, there are produced within the blood of the insect certain yeastlike bodies called blastocysts, which are carried in the circulation to all parts of the body. The yeastlike cells produce an early vegetative state in the development of the fungus. Cutworms showing no external sign disclose, when broken open, a brick-red powdery mass in the larval shell (fig. 210, *A*). This consists of "spherical or subspherical, somewhat reddish-colored, moderately thick-walled cells, the resting spores" (fig. 210, *B*, *C*). Experiments by Speare (1920) show the high infectivity of the spores on vigorous larvae.

TORRUBIELLA FUNGI

*Torrubiella lecanii* Johnston.—This fungus has vivid, yellow, erect, conical perithecia and is reported on hemispherical scale in Cuba and Puerto Rico.

*Torrubiella rubra* Pat. and Lagli.—This fungus[1] has purplish red perethecia. It has been found on an unidentified insect on citrus from Venezuela

[1] Identified by C. L. Shear.

in association with *Aschersonia goldiana* and *Sirosperma Hyprocrellae* Syd. On other hosts it is reported from Ecuador and Chile.

### PEGIOTRICHUM FUNGUS

*Pegiotrichum saccarinum* Raw.—This fungus[1] was found by the author on an unidentified scale on citrus at Vicosa, Brazil. The colorless spores are borne on tips of short stalks at the base of bundles of erect hyphae.

### ACROSTALAGMUS FUNGI

*Acrostalagmus albus* Pr.—This fungus is reported on brown scale on citrus in northern Italy. It consists of a woolly, white or slightly yellowish covering over the insect. It is somewhat similar in general growth to *Cephalosporium lecanii.*

*Acrostalagmus aphidum* Oud.—This species has been reported on the citrus-inhabiting aphids, cotton aphid, green peach aphid in Florida, and black citrus aphid in the Dominican Republic. (See Petch, 1925*b*; Marchionatto, 1941*a.*)

### RHINOTRICHUM FUNGUS

*Rhinotrichum album* Petch.—According to Petch (1931), this fungus is the same as *Sonatorrhodiella coccorum* Petch. It is reported on brown scale, green scale, species of Aleyrodids, and species of leaf hoppers in Ceylon. It forms on the scale a loose white pile of mycelium consisting of rigid erect stalks or conidiophores, and the mycelium spreads out on the leaf. (See *Rhinotrichum depauperatum,* under "Fungi of Mites.")

### METARRHIZIUM FUNGUS

*Metarrhizium anisopliae* (Metsch.) Sor.—This fungus, producing numerous powdery, wind-borne spores, is called green muscardine. On citrus, it is reported on one of the May beetles in Puerto Rico (Stevenson, 1918). It is related to the *Penicillium,* and in North America has been identified on more than sixty species of insects, mostly beetles. It has been grown in pure culture, and the spores have been applied with a dusting machine in order to start epidemics earlier than they would otherwise occur. Rorer (1913) in Trinidad found that distribution of this fungus early in the season increased the mortality of the insect known as "sugar-cane froghopper." In Puerto Rico, however, Stevenson concluded that its artificial distribution did not practically increase the mortality of the May beetle.

### CLADOSPORIUM FUNGI

It is doubtful whether species of *Cladosporium* as found on insects are to be accounted more than a saprophyte or, at most, a weak parasite. *Cladosporium aphidis* Thuem. has been reported on cotton aphid in California and Puerto Rico; on spirea aphid in California; on green peach aphid in Puerto Rico; and on cottony cushion scale in Mississippi. *Cladosporium herbarum* (Pers.) Lk. has also been reported on the last-named insect in Louisiana, and on red scale. Unidentified forms are reported on the cottony cushion scale,

[1] Identified by C. L. Shear.

California red scale, and citrus white fly. Watson (1914*b*) reported a *Cladosporium* on 80 per cent of a population of woolly white fly.

## BACTERIAL PARASITES OF INSECTS

A large number of bacteria have been reported in association with insects (Paillot, 1922; Steinhaus, 1942, 1946), and certain of these have been shown to cause definite diseases in insects of various kinds. The foul brood of bees caused by *Bacillus larvae* White and a honeybee disease produced by *Bacillus alvei* Cheshire and Cheyne are well-known examples. Other examples are a disease of hornworm[1] on tomato and tobacco, caused by *Bacillus spingidis* White; a disease of the June beetle, by *Micrococcus nigrofaciens* Northrup (1914); and septicemia of cutworms, by *Proteus noctuarum* (White) Bergey.

Recently a bacterium causing the milky disease in Japanese beetle has been investigated by White and Dutky (1940) and found to be effective in producing a high insect mortality. The causal organisms are two species of a spore-producing bacterium, *Bacillus popilliae* and *B. lentimorbus,* described by Dutky (1940). The relationship to the disease has been shown by inoculating several thousand healthy larvae. When healthy larvae come in contact with the dead larvae left in the soil they contract the disease, and a high mortality results. It has been found feasible to spread the disease artificially by means of spore dust derived from dead larvae. One and one-half million larvae have been used in producing more than 25,000 pounds of spore dust. Diseased adults average about five hundred million spores each, but larvae average about two billion spores each (Langford, Vincent, and Cory, 1942). It has recently been found that the adults, when actively migrating, carry the organism while in the process of becoming diseased; it is therefore suggested that adults be collected, inoculated, and liberated to spread the disease.

Another example is a rod-shaped bacterium causing a disease of epidemic proportions on the omniverous looper on avocados in San Diego County, California. Insects were readily killed by inoculations with pure cultures by spraying, rubbing, or injecting the insects.[2]

It is possible that a number of bacterial species on citrus insects will eventually be found to play a considerable part in natural control.[3]

Only two bacterial diseases of citrus insects have so far come to the author's attention: a disease of the citrus mealybug in Russia, and a disease of the California red scale in California.

### BACTERIAL DISEASE OF MEALYBUG

The citrus mealybug was found by Pospelov (1936)[4] to be infected by a red bacterium, identified as *Bacterium prodigiosum,* which was isolated and shown experimentally to be virulent for several species of *Pseudococcus.*

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[1] For scientific names of insects mentioned by their English names see table 49, p. 657.

[2] Unpublished work by Ira Ayres and D. F. Palmer.

[3] The possibility of finding bacterial diseases which may limit citrus insects has been voiced by several authors (Morrill and Back, 1912; and Fawcett, 1936, 1944).

[4] Referred to by Steinhaus (1942), p. 133.

## BACTERIAL DISEASE OF THE RED SCALE

A spore-forming bacterium, designated as Bacillus C,[1] has been found capable, under certain conditions, of killing California red scale (Sokoloff and Klotz, 1942). If we except the mealybug bacterium, this is, so far as is yet known, the first report of a scale insect infected with a disease-producing bacterium.

Bacillus C is a large (6 by $1\frac{1}{4}\mu$) gram-positive motile rod, which forms spores in the equatorial position. Its motility is usually lost after a few days of growth on ordinary media. It grows singly, in twos end to end, and in chains of four or more.

Under laboratory conditions, lemon fruits heavily infested with red scale which were immersed in a suspension of Bacillus C for two to four hours developed several days later a mortality that was high when compared with immersion in the same medium free from this bacterium. In some seasons in past years, especially during or following moist weather, the red scale has been noted to have a very high mortality from some hitherto unknown cause. One of these epidemics was reported by Ebeling in 1934, and fungi isolated by L. J. Klotz were suspected to be one of the factors at that time. It is believed now that this high mortality may have been caused by the Bacillus C. It is possible that this bacterium is in part the cause of epidemics of this kind when conditions are suitable for its abundant multiplication and spread to the insects. In preliminary field trials on trees sprayed with suspensions of bacteria or dusted with mixtures of spores and clay (Sokoloff and Klotz, 1942), the mortality of adult females was twice that of the corresponding checks. In time the difference between the sprayed and unsprayed trees disappeared. A species of bacterium apparently the same as the one introduced was recovered in cultures from 90 per cent of the recently killed insects tested.

Since the death of the scale in these experiments is found to be accompanied by a significant decrease of soluble-nitrate content, it is postulated that the lethal effect of the bacillus is accompanied by nitrate reduction to nitrite inside the insect. This is further indicated by the fact that certain red scales raised on sago palm or on detached lemons and grapefruit were found on analysis to have only a trace of nitrate and were resistant, while those raised under natural conditions had a greater nitrate content and proved to be susceptible. Moreover, when the scales were raised on sago palm which had been given abundant nitrate, the scales increased in nitrate content and became susceptible to the bacterium (Sokoloff and Klotz, 1943).

Previous observations on unusual red-scale mortality have been reported. As already mentioned, in California in 1934 the red scale was reduced by

[1] N. R. Smith, quoted in a letter from E. A. Steinhaus to L. J. Klotz, finds the organism to be a strain of *Bacillus cereus* and states: "It does reduce nitrates to nitrites vigorously in ordinary nutrient broth, but that is not unusual for this species." Steinhaus states: "*Bacillus cereus* is a very common soil organism and is known to cause disease in several insects."

some natural means to a very small population. It is now suspected that Bacillus C may have been one of the main factors in this natural epidemic in the orchards.

A heavy mortality of citricola scale was also noted by Quayle (1938) in California. He states: "Mortality occurred to an unprecedented extent in the more mature scales in the winter and early spring of 1934. Control work . . . was practically entirely omitted in 1934, 1935, and 1936. No such condition approaching this had occurred since citricola scale became a pest of citrus more than 20 years previous." The author[1] expressed at that time the possibility that the disease epidemic on red scale might be due to the activity of some bacterial organism.

A similar mortality and reduction of red scale in Palestine is reported by Carmin (1936). He states that in January, 1931, a high natural mortality of red scale was found even where no control measures had been used. Young as well as older scales shriveled and turned a dirty violet color, and the scale for that season appeared to be well controlled by some natural means. Three kinds of fungi, two species of *Aspergillus* and a *Cladosporium*, were mentioned as having a possible relation to this mortality, but the relationship was uncertain. It is stated that the scale at that time was not a serious pest in older orchards with heavy shade and well protected from winds.

The red scale in Guam was reported to be effectively suppressed in 1927,[2] presumably by a fungus, the identity of which was not reported. This fungus, it is further stated, was successfully established in the island at places where it had not formerly been evident. It is possible that here, as elsewhere, a bacterium may have been present.

## SUMMARY AND DISCUSSION

I have either briefly described or listed sixty-three fungi and two bacteria considered to be parasitic or semiparasitic on citrus insects, principally on the scale insects and white-fly larvae: thirteen are on various white flies; thirty-eight on scale insects; six on mealybugs; four on aphis; and eight on other citrus insects.

Some of these occur in more than one of these groups. Some of the fungi appear to produce serious epidemics, others to occur only occasionally and sporadically.

Some of these fungi appear to be specific obligate parasites, going into a resting stage as soon as the insect dies, whereas others may live part of their life in and on the insects and part of the time may live saprophytically. Some have been seen to penetrate quickly into the body of healthy insects, produce abundant mycelium, and then perfect their fruiting stages after the insect has been killed. This is indeed the manner in which most parasitic fungi develop their life histories in attacking living plants. There is first the penetration of live cells, the development of hyphae and mycelium, and then the

[1] Letter from H. S. Fawcett to T. Petch on sending him some dead California red scale, December 5, 1934.

[2] Ann. Rept. of Guam Exper. Sta. for 1927.

perfection of the fruiting stages in or on the dead part killed by the parasite. Some of these entomogenous fungi appear to be important in bringing about a certain degree of natural control which in favorable, special situations amounts to satisfactory commercial control. Others are of only minor importance, and still others are of doubtful value and may be little more than saprophytes. Some of these, especially the fungi on larvae of *Dialeurodes*, or on white flies in conditions such as obtain in Florida, have been spread artificially to increase their efficiency at certain seasons of lag. It has been pointed out, however, from certain recent observations, that the efficiency of entomogenous fungi as controlling purple scale cannot be fairly judged under conditions of phenomenal increase of this scale when trees are sprayed with bordeaux mixture or other residue-depositing fungicides. Other factors, which likewise make conditions more favorable for the scales, appear to account for a considerable part of this increase.

Much further research is needed in this phase of biological control of insects, a phase which has been badly neglected, possibly because mycologists and plant pathologists have considered it to be somewhat outside their field and because economic entomologists are busy with insect parasites and are usually not familiar with the fungi or in a position to take up the investigation. Also, there appears to have been in the past a tendency among economic entomologists to judge the possibilities by the failure of some experiments to show a high degree of control. The failure to attain increased mortality by artificial distribution of the chinch-bug fungus, *Beauvaria globulifera*, has often been cited as an example of what may be expected from entomogenous fungi. It has been pointed out above that this result might have been expected from a fungus of this kind, which has many hosts and which produces such an abundance of wind-borne spores that it may become widespread and reach a "saturation point" under almost all conditions suitable for infection. The negative result from experiments with this fungus is not necessarily a criterion by which to judge possibilities with others. More attention has recently been directed to this subject by reason of the success scored against the milky disease of the Japanese beetle (Beard, 1945).

What is needed is to determine more definitely not only the role which these entomogenous fungi and bacteria play in natural control, but also to explore further the possibilities of increasing their efficiency by artificial spread in situations where the "saturation point" is not reached under natural conditions. It is also important to determine how far the limiting factors for infection may be changed economically in the direction of greater control.

Much attention is being given to the discovery, introduction, and artificial spreading of entomophagous insects and to finding ways of increasing their efficiency. The comparatively few that have afforded control have justified this large effort. Greater attention should be directed to exploring the possibilities with similar work on various insect-destroying fungi and bacteria, and possibly on insect-destroying viruses. More coöperative research by plant pathologists and entomologists should yield important results in this largely unexplored field.

TABLE 49

COMMON NAMES, WITH SCIENTIFIC EQUIVALENTS, OF THE INSECTS AND MITES MENTIONED

| | |
|---|---|
| alfalfa weevil | *Hypera postica* (Gyll.) |
| avocado red mite | *Paratetranychus yothersi* (McG.) |
| black citrus aphid | *Toxoptera aurantiae* Fonsc. |
| black-headed fireworm | *Rhopobota naevana* (Hbn.) |
| black parlatoria scale | *Parlatoria zizyphus* (Lucas) |
| black scale | *Saissetia oleae* (Bern.) |
| black thread scale | *Ischnaspis longirostris* (Sign.) |
| California red scale | *Aonidiella aurantii* (Mask.) |
| chaff scale | *Parlatoria pergandii* Comst. |
| chinch bug | *Blissus leucopterus* (Say) |
| citricola scale | *Coccus pseudomagnoliarum* (Kuw.) |
| citrophilus mealybug | *Pseudococcus gahani* Green |
| citrus black fly | *Aleurocanthus woglumi* Ashby |
| citrus mealybug | *Pseudococcus citri* (Risso) |
| citrus red mite | *Paratetranychus citri* (McG.) |
| citrus rust mite | *Phyllocoptruta oleivorus* (Ashm.) |
| citrus white fly | *Dialeurodes citri* (Ashm.) |
| cloudy-winged white fly | *Dialeurodes citrifolii* (Morg.) |
| clover-leaf weevil | *Hypera punctata* (F.) |
| corn earworm | *Heliothis armigera* (Hbn.) |
| cotton aphid | *Aphis gossypii* Glov. |
| cottony cushion scale | *Icerya purchasi* Mask. |
| dictyospermum scale | *Chrysomphalus dictyospermi* (Morg.) |
| Florida red scale | *Chrysomphalus ficus* Ashm. |
| Florida wax scale | *Ceroplastes floridensis* Comst. |
| froghopper | *Tomaspis varia* (Fabr.) |
| Glover's scale | *Lepidosaphes gloverii* (Pack.) |
| grain beetle | *Anisoplia austriaca* Hbst. |
| green peach aphid | *Myzus persicae* (Sulz.) |
| green scale | *Coccus viridis* (Green) |
| hemispherical scale | *Saissetia hemisphaerica* (Targ.) |
| hornworm of tobacco | *Protoparce sexta* (Johan.) |
| hornworm of tomato | *Protoparce quinquemaculata* (Haw.) |
| inconspicuous white fly | *Bemisia inconspicua* (Quaint.) |
| ivy scale | *Aspidiotus hederae* (Vallot) |
| Japanese beetle | *Popillia japonica* Newm. |
| June beetle | *Serica fimbriata* Lec.<br>*Serica alternata* Lec. |
| long scale | *Lepidosaphes gloverii* Pack. |
| May beetle | *Phyllophaga citri* Smyth |
| May beetles | *Phyllophaga (Lachnosterna)* sp. |
| mealybug destroyer | *Cryptolaemus montrouzieri* Muls. |
| Mexican mealybug | *Phenacoccus gossypii* T. and C. |
| mulberry white fly | *Tetraleurodes mori* (Quaint.) |
| nigra scale | *Saissetia nigra* (Nietn.) |
| obscure scale | *Chrysomphalus obscurus* (Comst.) |

| | |
|---|---|
| omnivorous looper | *Sabulodes caberata* Guenee |
| oyster-shell scale | *Lepidosaphes ulmi* (Linn.) |
| potato leaf hopper | *Empoasca fabae* (Harr.) |
| potato aphid | *Macrosiphum solanifolii* (Ashm.) |
| purple scale | *Lepidosaphes beckii* (Newm.) |
| Putnam scale | *Aspidiotus ancylus* (Putn.) |
| pyriform scale | *Protopulvinaria pyriformis* (Ckll.) |
| red-legged earth mite | *Halotydeus destructor* (Tucker) |
| rufous scale | *Selenaspidus articulatus* (Morg.) |
| San Jose scale | *Aspidiotus perniciosus* Comst. |
| snow scale | *Chionaspis citri* Comst. |
| soft brown scale | *Coccus hesperidum* Linn. |
| Spanish red scale | *Chrysomphalus dictyospermi* (Morg.) |
| spirea aphid | *Aphis spireacola* (Patch) |
| sugar-cane aphis | *Aphis sacchari* Zehnt |
| sugar-cane froghopper | *Tomaspis saccharina* Dist. |
| sugar-cane mealybug | *Pseudococcus boninsis* (Kuw.) (gray)<br>*Trionymus sacchari* (Ckll.) (pink) |
| sweet-potato white fly | *Bemisia inconspicua* (Quaint.) |
| vedalia | *Rodolia cardinalis* (Muls.) |
| velvet-bean caterpillar | *Anticarsia gemmatilis* (Hbn.) |
| walnut aphid | *Chromaphis juglandicola* (Kltb.) |
| wax scale | *Ceroplastes floridensis* (Comst.) |
| western spotted cucumber beetle | *Diabrotica soror* (Lec.) |
| woolly white fly | *Aleurothrixus howardi* (Quaint.) |

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## Chapter XIV

# INSECTS AND MITES AND THEIR CONTROL

BY

ALFRED M. BOYCE

Citrus insects and mites[1] have demanded attention from growers and entomologists since the beginning of citrus culture in the United States. Because the pests are harmful to trees and fruit, pest-control measures have been essential to the growing of healthy trees and sound fruit. Requisite studies on the biology and control of citrus pests throughout the years have contributed materially to the development of principles and practices of pest control in general.

That citrus pests are important to the citrus industry has been recognized for more than half a century; and within that time pest control has made its chief advances, in parallel with the growth of the industry in the United States. The citrus tree, having year-round foliage and flourishing in a mild climate, is especially liable to attacks by pests; and the same conditions make control difficult: the pest population is nearly always on the increase, and because the trees lack a winter period of dormancy many of the otherwise effective insecticides cannot be used. Besides their harmful effects on the tree itself, which are continuous from one year to the next, several of the pests affect the quantity and quality of each year's crop of fruit. While different standards of fruit quality are recognized in different countries, the highest quality, at least in California, is invariably associated with the most successful pest-control practice.

In the broader field of economic entomology, measures taken to reduce damage by citrus pests have had very important results in the achievements of biological control, in the development of petroleum oil sprays, in tree fumigation, plant quarantine, insect eradication, studies of insect resistance to insecticides, and improvements in the machinery for applying insecticides.

One of the early pests of citrus in California was the cottony cushion scale, *Icerya purchasi* Mask., from Australia; and the success that was attained with the introduction of its enemy the vedalia, *Rodolia cardinalis* (Muls.), also from Australia, gave a strong impetus to the general development of biological control. Later, the citrophilus mealybug, *Pseudococcus gahani* Green, and the black scale, *Saissetia oleae* (Bern.), on citrus in the coastal areas particularly, were likewise controlled by the introduction of natural enemies.

Petroleum oil in the form of kerosene was used against citrus insects in Florida as early as 1865. Tests were made with the same material against the cottony cushion scale and other scale insects in California in the early

[1] For a general reference on this subject see H. J. Quayle, *Insects of Citrus and Other Subtropical Fruits* (Comstock Pub. Co., Inc., Ithaca, N.Y., 1938; 583 pp.), and for reference to current conditions of citrus pests and recommendations for control in California see the California Fruit Growers' Exchange *Pest Control Circular*, issued monthly.

'eighties. Distillates and other types of petroleum oils later came into use. Developments have continued, and it has been against citrus scale pests that some of the most important advances have been made in the use of petroleum oil sprays.

Orchard or tree fumigation was first tried as a protection against citrus pests, and with few exceptions this important method of pest control has been employed, and further developed, exclusively for the protection of citrus trees. Here again, the cottony cushion scale was the insect combated, occasioning the first use of hydrocyanic acid as a fumigant.

The cottony cushion scale likewise occasioned early recognition of the value of plant quarantine. Citrus growers in southern California sustained severe losses from the activities of this insect, and hence pressed for legislation to prevent the introduction of other injurious species. Once a pest is established in a new country, the toll it takes from the grower, either in the form of direct loss by reason of the damage it does or in the cost of control measures, may continue indefinitely. Hence it is important to consider the feasibility of attempting eradication of a potentially serious introduced pest as soon as it is found in another country or region. Here again, it is in connection with citrus culture that some of the most extensive and successful eradication campaigns have been conducted. The eradication of the Mediterranean fruit fly, *Ceratitis capitata* (Wied.), and of a bacterial disease, the citrus canker, *Pseudomonas citri* Hasse, in Florida, represent the outstanding achievements under this category. Another notable example is the eradication of the citrus white fly, *Dialeurodes citri* (Ashm.), in California.

Of the problems confronting entomologists in recent years, one of the most perplexing has resulted from the fact that successful control for a pest may be developed and found satisfactory for a time, but later becomes less effective. For example, of scale insects attacking citrus trees in southern California, three which formerly were well controlled by hydrocyanic acid fumigation have become so tolerant to fumigation, in some of the affected areas, as to necessitate other methods of control. Equally striking is the relatively recent development of resistance of the citrus thrips, *Scirtothrips citri* (Moult.), to tartar emetic.

Finally, citrus pest control has necessitated the development of special equipment and methods for applying insecticides. Covering the tree with a tent and liberating a gas beneath, as in fumigation, is practical because the citrus tree is of medium size and compact growth, and is always in leaf. For about fifty years, the fumigation tents were pulled over the trees by hand; but mechanical tent pullers have been devised which now are in general use. With the machine, 75 or more trees can be covered in an hour. In spraying citrus trees for control of scale insects and mites the modern large-capacity, high-pressure, mobile spray equipment includes a hydraulically operated telescoping mast which supports a platform for the "tower spraymen." The "towers" may usually be extended to a maximum height of 26 to 30 feet above the ground, and may readily be adjusted by the spraymen to the height necessary for satisfactory spray coverage of the tops of citrus trees.

Another mechanical aid, the boom, is rapidly coming into use. From 6 to 34 spray nozzles—the number depends on the design—are mounted on a vertical or near-vertical boom in such a way that they mechanically oscillate horizontally, vertically, or with a circular motion while discharging spray material. Boom application is satisfactory where thorough spray coverage of the inside of the tree is not so essential.

Formerly, the usual machine for applying dusts to trees delivered a relatively small volume of air at high velocity through one or two small tubular outlets which were manipulated by hand. The machine now generally used for dusting citrus trees delivers a large volume of air at a relatively low velocity through two "fishtails," fixed in their position on the duster, which direct the material uniformly against two tree rows, to right and left, as the machine moves slowly along between them. A modification of this machine consists of fixed spray nozzles in the fishtail outlets, and a spray tank and pump. This machine, which is known as a "spray duster," can apply either liquid or dust, separately or in combination. When only liquid is used, as small a quantity as 20 gallons of spray mixture to an acre can be applied, the spray being well distributed on the outer portions of the tree by the blast of air from the machine.

It is a recognized characteristic of insects as a group of animals that they succeed in adapting themselves to their surroundings, or in changing their habits to meet new conditions. The pests of citrus trees are no exception, and some of their adaptations account for the fact that new control problems are continually arising. Some have already been referred to; and there are others scarcely less important. The citrus red mite, or red spider, *Paratetranychus citri* (McG.), was formerly controlled satisfactorily by sulfur, applied either in the form of a dust or a spray, but sulfur is no longer relied upon as a satisfactory control material. In recent years this mite has become a serious pest in citrus-growing areas in certain interior valley sections of California, as at Riverside and Redlands; but whether this represents a cyclic or a permanent condition remains to be determined. The citrus thrips is now a more serious threat to lemon orchards than formerly, and occurs over a wider range of climatic conditions. Another species, the greenhouse thrips, *Heliothrips haemorrhoidalis* Bouché, until recently a minor pest on citrus trees in California, has become persistent in a certain area in San Diego and Ventura counties. The pink scavenger worm, *Pyroderces rileyi* (Wals.), a typical scavenger species only occasionally found on oranges prior to 1940, has become of importance as a pest on Valencia oranges in Orange County, California. The orange tortrix, *Argyrotaenia citrana* (Fern.), is another California citrus pest that has become more widely distributed and more injurious in the decade under discussion. Pests that appear as new to a particular area are not so common as formerly, because of the effectiveness of the quarantine service, but occasionally a new pest makes its appearance either through accidental introduction or as a native insect that becomes established on a new host. In 1937, a fairly widespread occurrence of the citrus bud mite, *Aceria sheldoni* (Ewing), was reported in California, but how or whence it

came is not yet known. It was determined as a pest on citrus in Australia soon after it was found in California.

The examples given above will serve to illustrate why the citrus grower, at least in California, is still confronted with problems in citrus pest control. Succeeding generations of citrus growers in this State are paying more and more attention to pests that affect adversely their trees and crops.

## GEOGRAPHICAL DISTRIBUTION OF CITRUS PESTS

Two factors chiefly determine the range over which insects become permanently established, namely, food and climate. Their ways of distributing themselves depend upon their own powers of movement and a variety of external factors such as wind, birds, other insects, and man in his cultural operations within an orchard or through commerce between distant places. Since most of the present areas of commercial citrus production are rather remote from the area where the citrus tree is native, the pests likewise have become widely distributed from their native habitat. Introduced pests are often the most serious menaces because in a new environment the biological equilibrium established through a long period of time is likely to be upset. The equilibrium may be regained if it is dependent upon some factor that can be transferred from the old environment to the new one: examples are represented by the introduction of insect enemies to control the cottony cushion scale, *Icerya purchasi* Mask., the citrophilus mealybug, *Pseudococcus gahani* Green, and the black scale, *Saissetia oleae* (Bern.). (See chap. xii.)

The concentration of citrus plantings in well-defined areas in different parts of the world has supplied conditions favorable to the food supply of insect pests. Although the range in climatic conditions where commercial citrus culture is practiced may not appear great, the variation is sufficient to effect sharply the establishment of many of the pests. If the climatic conditions under which citrus is grown in different parts of the world may be divided as arid, semiarid, and humid, the species of citrus insects may be roughly grouped by the same conditions. In fact, only a relatively small number of citrus insects and mites may be considered important in both a semiarid and a humid climate. The purple scale, *Lepidosaphes beckii* (Newm.), and the citrus red mite, *Paratetranychus citri* (McG.), are interesting examples of an insect and a mite that are important in citrus-growing areas of both semiarid California and humid Florida. Nevertheless, in California both species appear to be restricted to conditions of climate within particular areas; the purple scale is more narrowly limited than the citrus red mite. In southern California there are more or less contiguous plantings of citrus from the coast to sixty or seventy miles inland, yet the purple scale gradually diminishes as a pest until it disappears completely at a distance of thirty or forty miles from the coast. Possibly the sixty years of its establishment in California has not been a long enough time to fix the final range of this insect. The citrus red mite is an important pest in all semiarid citrus localities in southern California; it does not occur, however, in the semiarid citrus localities in the central part of the State.

The distribution of several other important pests of citrus trees is apparently governed by the variation in climate within the California citrus areas. Some of them are even restricted in distribution to parts of a single county. The black scale and the citrus red mite, for example, are serious pests in those parts of Riverside County where most of the citrus is grown, but in another part, the Coachella Valley desert area, these same pests are not recorded on citrus. It is true that these represent wide differences in climatic conditions, chiefly the variation in maximum and minimum temperatures and rainfall. If evidence of the relationships between climatic conditions and insect pests were available in only one county, the possibility of other, unknown, factors might not be ignored. But evidence is available in many places throughout the California citrus area. To follow the black scale further, it is not a pest on citrus trees in Tulare County, where summer temperatures are appreciably higher than in those parts of Riverside County where it flourishes but not so high as in the desert area where the insect does not exist on citrus. However, in Tulare County the black scale occurs as an important pest on the more favored host, the olive, which grows in close proximity to citrus. It has thus had opportunity to reach the citrus trees; in fact, it is sometimes found on citrus trees adjoining heavily infested olive trees; but it has not become a pest, apparently because of the unfavorable climatic conditions and the slightly less favorable host plant. The citricola scale, *Coccus pseudomagnoliarum* (Kuw.), thrives under the climatic conditions obtaining in Tulare County, but it does not occur in the coastal area of southern California. The citrus thrips, *Scirtothrips citri* (Moult.), is also for the most part limited to the same general conditions, while several of the species of mites and the aphids of citrus trees thrive best in a more nearly coastal climate.

## THE MORE IMPORTANT PESTS OF CITRUS IN DIFFERENT PARTS OF THE WORLD

The distribution of citrus pests in different parts of the world may be indicated by listing some of the more common and important species that occur in different countries. It is not feasible to attempt to list all the species that are known to occur on citrus. The list presented here is, of course, open to objections and criticisms, because the relative importance of the species may not be based on clear-cut distinctions, and different criteria may have been employed by different persons in arriving at their conclusions. Additions to the list are probable.

The order of importance should be expected to change from time to time. For example, it is to be noted that in California the black scale, *Saissetia oleae* (Bern.), is now much less important than it was ten years ago, when it was the major pest of citrus. The principal reasons for its present status are the effectiveness of imported parasites in attacking it, and the general use of rigorous pest-control measures necessitated by the increased importance of red scale, *Aonidiella aurantii* (Mask.). in many localities, and of the citrus bud mite, *Aceria sheldoni* (Ewing), in others. Where control

methods are extensively practiced, the amount of money expended in combating the different species is a reasonably safe criterion, provided due recognition is given to the fact that a single treatment is often effective in the control of several species. With these shortcomings in mind, the following list is presented.

THE MORE IMPORTANT INSECTS AND MITES INJURIOUS TO CITRUS

| COMMON NAME | SCIENTIFIC NAME |
|---|---|
| **California** | |
| California red scale | *Aonidiella aurantii* (Mask.) |
| Citrus red mite | *Paratetranychus citri* (McG.) |
| Citrus bud mite | *Aceria sheldoni* (Ewing) |
| Purple scale | *Lepidosaphes beckii* (Newm.) |
| Black scale | *Saissetia oleae* (Bern.) |
| Citrus thrips | *Scirtothrips citri* (Moult.) |
| Citricola scale | *Coccus pseudomagnoliarum* (Kuw.) |
| Green citrus aphid | *Aphis spiraecola* Patch |
| Melon aphid | *Aphis gossypii* Glov. |
| Orange tortrix | *Argyrotaenia citrana* (Fern.) |
| Citrus mealybug | *Pseudococcus citri* (Risso) |
| Baker mealybug | *Pseudococcus maritimus* (Ehrh.) |
| Long-tailed mealybug | *Pseudococcus adonidum* (Linn.) |
| Citrophilus mealybug | *Pseudococcus gahani* Green |
| **Arizona** | |
| Citrus thrips | *Scirtothrips citri* (Moult.) |
| **Texas** | |
| Citrus rust mite | *Phyllocoptruta oleivora* (Ashm.) |
| Texas citrus mite | *Anychus clarki* McG. |
| California red scale | *Aonidiella aurantii* (Mask.) |
| Florida red scale | *Chrysomphalus ficus* Ashm. |
| Fire ant | *Solenopsis xyloni* var. *maniosa* Wheeler |
| **Florida** | |
| Purple scale | *Lepidosaphes beckii* (Newm.) |
| Citrus rust mite | *Phyllocoptruta oleivora* (Ashm.) |
| Citrus red mite (Purple mite) | *Paratetranychus citri* (McG.) |
| Florida red scale | *Chrysomphalus ficus* Ashm. |
| Citrus white fly | *Dialeurodes citri* (Ashm.) |
| Cloudy-winged white fly | *Dialeurodes citrifolii* (Morg.) |
| Six-spotted mite | *Tetranychus sexmaculatus* Riley |
| Citrus mealybug | *Pseudococcus citri* (Risso) |
| Green citrus aphid | *Aphis spiraecola* Patch |
| **Mexico and Central America** | |
| Florida red scale | *Chrysomphalus ficus* Ashm. |
| Purple scale | *Lepidosaphes beckii* (Newm.) |
| California red scale | *Aonidiella aurantii* (Mask.) |
| Rufous scale | *Selenaspidus articulatus* (Morg.) |
| Citrus black fly | *Aleurocanthus woglumi* Ashby |
| Mexican fruit fly | *Anastrepha ludens* (Loew) |

| COMMON NAME | SCIENTIFIC NAME |
|---|---|
| Citrus rust mite | *Phyllocoptruta oleivora* (Ashm.) |
| Leaf-cutting ants | *Atta* species |
| **SOUTH AMERICA** | |
| Purple scale | *Lepidosaphes beckii* (Newm.) |
| Florida red scale | *Chrysomphalus ficus* Ashm. |
| Mediterranean red scale | *Chrysomphalus dictyospermi* (Morg.) |
| California red scale | *Aonidiella aurantii* (Mask.) |
| Rufous scale | *Selenaspidis articulatus* (Morg.) |
| Snow scale | *Chionaspis citri* Comst. |
| Delta scale | *Lecanium deltae* Lizer |
| Citrus rust mite | *Phyllocoptruta oleivora* (Ashm.) |
| South American fruit fly | *Anastrepha fraterculus* (Wied.) |
| Mediterranean fruit fly | *Ceratitis capitata* (Wied.) |
| Black citrus aphid | *Aphis citricidus* (Kirk.) |
| Leaf-cutting ants | *Atta* species |
| **SPAIN** | |
| Mediterranean red scale | *Chrysomphalus dictyospermi* (Morg.) |
| Purple scale | *Lepidosaphes beckii* (Newm.) |
| Citrus mealybug | *Pseudococcus citri* (Risso) |
| Glover's scale | *Lepidosaphes gloverii* (Pack.) |
| Black parlatoria scale | *Parlatoria zizyphus* (Lucas) |
| Black scale | *Saissetia oleae* (Bern.) |
| **ITALY AND NORTH AFRICA** | |
| Mediterranean red scale | *Chrysomphalus dictyospermi* (Morg.) |
| Purple scale | *Lepidosaphes beckii* (Newm.) |
| Citrus mealybug | *Pseudococcus citri* (Risso) |
| Black parlatoria scale | *Parlatoria zizyphus* (Lucas) |
| Black scale | *Saissetia oleae* (Bern.) |
| Ivy scale | *Aspidiotus hederae* (Vallot) |
| **EGYPT AND PALESTINE** | |
| Florida red scale (Black scale) | *Chrysomphalus ficus* Ashm. |
| California red scale | *Aonidiella aurantii* (Mask.) |
| Purple scale | *Lepidosaphes beckii* (Newm.) |
| Hibiscus mealybug | *Phenacoccus hirsutus* Green |
| Citrus mealybug | *Pseudococcus citri* (Risso) |
| Florida wax scale | *Ceroplastes floridensis* Comst. |
| Chaff scale | *Parlatoria pergandii* Comst. |
| **SOUTH AFRICA** | |
| California red scale | *Aonidiella aurantii* (Mask.) |
| South African citrus thrips | *Scirtothrips aurantii* Faure |
| Soft (or: Soft brown) scale | *Coccus hesperidum* Linn. |
| Bollworm | *Heliothis armigera* (Hbn.) |
| False codling moth | *Argyroploce leucotreta* Meyr. |
| Florida red scale (Circular purple scale) | *Chrysomphalus ficus* Ashm. |
| Purple scale (Mussel scale) | *Lepidosaphes beckii* (Newm.) |
| Black citrus aphid | *Toxoptera aurantii* (Fonsc.) |
| Citrus mealybug | *Pseudococcus citri* (Risso) |

### South Africa (*Continued*)

| COMMON NAME | SCIENTIFIC NAME |
|---|---|
| Mediterranean fruit fly | *Ceratitis capitata* (Wied.) |
| Natal fruit fly | *Pterandrus rosa* (Ksh.) |
| Citrus snout beetle | *Sciobius granosus* Fahr. |

### Australia

| | |
|---|---|
| California red scale | *Aonidiella aurantii* (Mask.) |
| White wax scale | *Ceroplastes destructor* Newst. |
| Snow scale (White louse) | *Chionaspis citri* Comst. |
| Black scale (Brown scale) | *Saissetia oleae* (Bern.) |
| Soft (or: Soft brown) scale | *Coccus hesperidum* Linn. |
| Dicky rice weevil | *Maleuterpes phytolymus* Olliff |
| Bronze orange bug | *Rhoecocoris sulciventris* Stahl. |

### Tropical Asia

| | |
|---|---|
| Purple scale | *Lepidosaphes beckii* (Newm.) |
| Snow scale | *Chionaspis citri* Comst. |
| Black parlatoria scale | *Parlatoria zizyphus* (Lucas) |
| Chaff scale | *Parlatoria pergandii* Comst. |
| California red scale | *Aonidiella aurantii* (Mask.) |
| Pulvinaria scale | *Pulvinaria polygonata* Ckll. |
| Green coffee scale | *Coccus viridis* (Green) |
| Orange spiny white fly | *Aleurocanthus spiniferus* (Quaint.) |
| Citrus psylla | *Diaphorina citri* Kuway |
| Weevil | *Hypomeces squamosus* Fah. |
| Citrus leaf miner | *Phyllocnistis citrella* Staint. |
| Moth borer | *Citripestis sagittiferella* Moore |
| Citrus bark borer | *Agrilus occipitalis* Esch. |
| Lemon butterfly | *Papilio demoleus* Linn. |
| Formosan fruit fly | *Chaetodacus ferrugineus* var. *dorsalis* Hendel |

### China

| | |
|---|---|
| Citrus leaf miner | *Phyllocnistis citrella* Staint. |
| Citrus trunk borer | *Melanauster chinensis* Först. |
| Black parlatoria scale | *Parlatoria zizyphus* (Lucas) |
| Red wax scale | *Ceroplastes rubens* Mask. |
| Orange spiny white fly | *Aleurocanthus spiniferus* (Quaint.) |
| Cottony cushion scale | *Icerya purchasi* Mask. |
| Black and red leaf miner | *Throscoryssa citri* Maulik |
| Citrus stinkbug | *Rhynchocoris humeralis* Thunb. |
| Citrus leaf caterpillar | *Papilio polytes* Linn. |
| Black citrus aphid | *Aphis citricidus* (Kirk.) |

### Japan

| | |
|---|---|
| Yanone scale | *Prontaspis yanonensis* (Kuw.) |
| Red wax scale | *Ceroplastes rubens* Mask. |
| Orange pulvinaria scale | *Pulvinaria aurantii* Ckll. |
| Chaff scale | *Parlatoria pergandii* Comst. |
| Aspidistra scale | *Pinnaspis aspidistrae* (Sign.) |
| Glover's scale | *Lepidosaphes gloverii* (Pack.) |
| Orange spiny white fly | *Aleurocanthus spiniferus* (Quaint.) |
| Marlatt white fly | *Aleurolobus marlatti* (Quaint.) |
| Citrus leaf miner | *Phyllocnistis citrella* Staint. |

## GROUPS OF INSECTS AND MITES

The insects and mites discussed in the following pages represent most of the commoner and more important ones that attack citrus trees. All that are mentioned cause injury in one or more of the commercial citrus regions of the world. Many species not mentioned may occasionally be important either in localized or general areas. The arrangement here followed is to group the pests in accordance with the general manner in which they attack the tree.



Information on control of the different species is given in connection with the discussion of each. However, further details on control, that is, on materials and the methods of applying them, are given further on (pp. 769–802). The details of control methods are given primarily for conditions in California. General comments are made on control in other regions; but not detailed directions, mainly because pest control in certain regions and countries is so complex as to require extended discussion, and because of the differences in economic conditions in various countries.

Even for one citrus-growing region, such as California, certain details of control that are applicable at present may not be entirely applicable a short time hence. Nevertheless, it is worth while to record specific directions for control as practiced at a particular time (here, 1948) for a particular region, such as California, where in one county alone the cost of the materials used against citrus pests, and of applying them, is more than $1,500,000 annually, and, in the State, more than $5,000,000 annually. Certain species are discussed only briefly, and control methods for them are not given, although they are more or less important pests, because none may be practiced in the countries where the pests occur.

## GROUP I

Mites, p. 674; thrips, p. 686; scale insects, p. 697; mealybugs, p. 728; white flies, p. 731; psyllids, p. 734; aphids, p. 735; leaf hoppers, p. 738; plant bugs, p. 739; and fruit-piercing moths, p. 741, that cause injury by sucking

the plant juices from the tree and (or) its fruit, some of which species scar the surface of foliage and (or) fruit.

## MITES

Mites are among the more important pests of citrus in the United States, but not in the Mediterranean region, South Africa, and Australia. The citrus rust mite, *Phyllocoptruta oleivora* (Ashm.), is the most injurious member of this group in Florida and other Gulf states, while the citrus red mite, *Paratetranychus citri* (McG.), is the ranking species in California. Mites occur chiefly in the coastal or near-coastal areas of California; in fact, none of the important species discussed here are even known to occur in interior sections such as the Coachella, Imperial, San Joaquin, and Sacramento valleys.

### Citrus Rust Mite, *Phyllocoptruta oleivora* (Ashm.)

Of mites which attack citrus throughout the world, the citrus rust mite is the most widely distributed species. (For general discussion of this mite see Yothers and Mason, 1930.) It is the most important of all the mites attacking citrus in Florida and the other Gulf states. It ranks second in importance as a pest of citrus in Florida, and first in Texas. A slight attack of the rust mite in Florida results in a grade of fruit known as "golden." When a severe attack occurs on young fruit, a "black russet" develops. When the rust mite injury is excessive on young grapefruit, it develops into what is known as "shark skin." In California, the rust mite has sporadically caused damage on lemons and oranges in several coastal localities. However, during the past few years infestations have persisted in these localities. It more often occurs on the lemons, producing a characteristic silvery effect; and hence it is known locally as the "silver mite" (fig. 211). It is of some importance in Queensland, where its work results in dark-brown oranges which are called "Maori" oranges, the mite itself being known as the "Maori mite." It occurs also in the East Indies, Mexico, Central and South America, Hawaii, the Philippines, China, and Japan.

The list of preferred host plants, in the order of severity of infestation, is, according to Yothers and Mason (1930): (1) lemon, (2) lime, (3) citron, (4) grapefruit, (5) sweet orange, (6) sour orange, (7) tangerine, (8) satsuma.

*Life history.*—The eggs occur on the fruits, usually in the pits or depressions and also on the leaves. They are semitransparent or pale transluscent yellow, and spherical in shape. About 30 eggs are laid by each individual, and they require from three to seven days to hatch. There are four developmental stages, and the period from egg to adult is about seven to fourteen days, depending on the temperature. The adult mite is about 1/200 inch long, wormlike in shape and yellowish in color (fig. 212). It has two pairs of short legs at its fore end and a pair of lobes on the last segment of its body. Parthenogenetic reproduction must occur, since males have not been recorded. This mite lives superficially on the fruit, leaves, and green twigs, in contrast to the closely related citrus bud mite, which inhabits protected locations. In

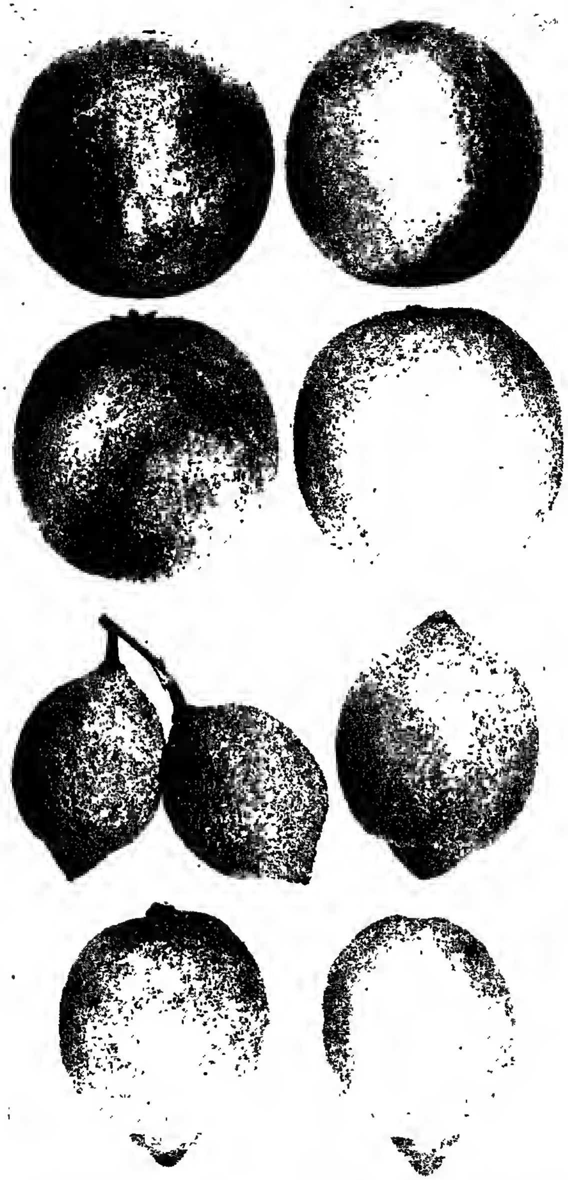

Fig. 211. Oranges (*above*) and lemons (*below*) showing typical injury caused by citrus rust mite, *Phyllocoptruta oleivora* (Ashm.). In each group, uninjured fruit (*lower right*) is included for comparison.

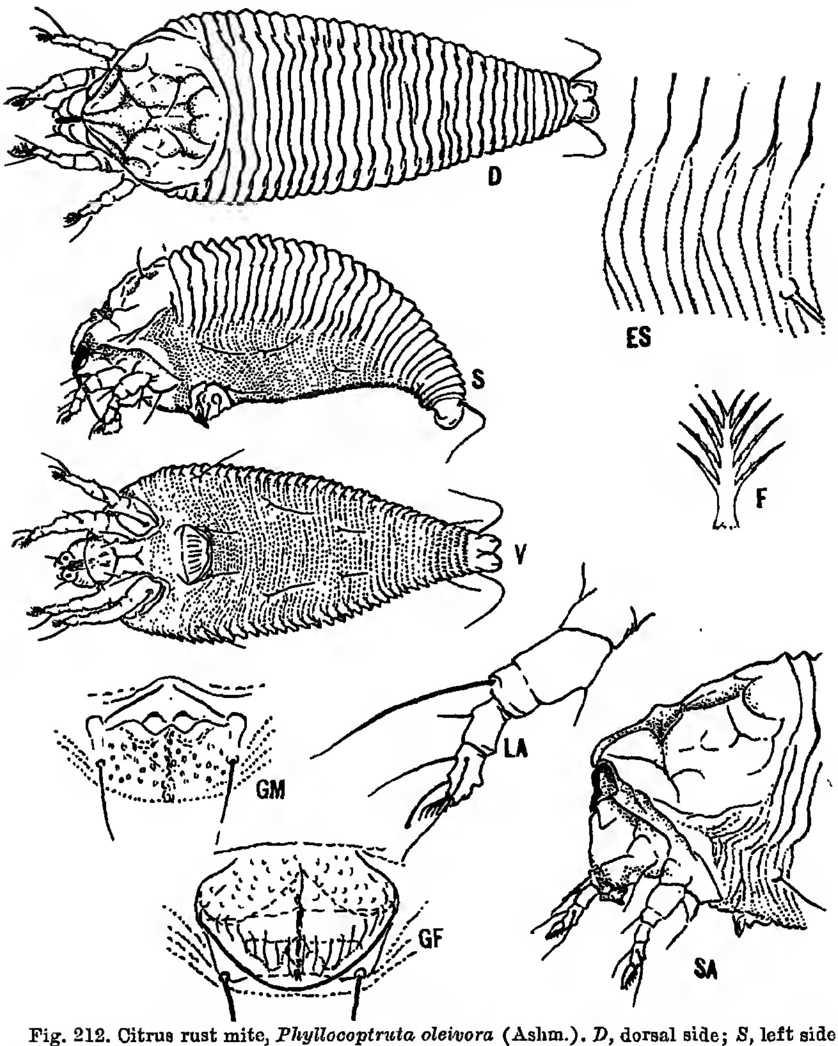


Fig. 212. Citrus rust mite, *Phyllocoptruta oleivora* (Ashm.). *D*, dorsal side; *S*, left side; *V*, ventral view; *GM*, male genitalia; *GF*, female genitalia; *ES*, detail of skin on side; *F*, featherclaw; *LA*, left foreleg; *SA*, left side of anterior section more or less turned ventrad. (After Keifer.)

Florida, the citrus rust mite is present on the citrus tree throughout the year and is most numerous in June and early July, least in January and February.

*Control.*—Sulfur is the principal material everywhere relied upon for control of the citrus rust mite. In Florida, from three to six applications annually are usually needed for satisfactory control. The sulfur may be applied as dust, as wettable sulfur at a dosage of 5 to 10 pounds plus either liquid

lime sulfur at 1 to 2½ gallons or dry lime sulfur at 3 to 8 pounds per 100 gallons of water, or as wettable sulfur at 5 to 10 pounds per 100 gallons in combination with certain materials needed for other purposes. The dosage of the various sulfur preparations and their use together is varied in accordance with the season and for other reasons. (See section on Florida spray-and-dust schedule, p. 798 below.)

In Texas, the usual practice is to dust with sulfur at thirty-day intervals during April, May, and June, using from 40 to 60 pounds per acre for each application (Friend, 1946). When control is necessary in California, either sulfur dust at a dosage of 50 to 75 pounds per acre, or 1½ gallons of lime sulfur plus 4 to 8 pounds of wettable sulfur per 100 gallons of water, is used. In this State there is hazard of injury from sulfur when high temperatures occur within several weeks after the treatment.

Petroleum oil sprays as used for control of other pests on citrus afford but temporary control of this mite.

### Citrus Bud Mite, *Aceria sheldoni* (Ewing)

The citrus bud mite is a species that was first recognized as a pest of citrus in Ventura County, California, in 1937. (For general discussion of this mite see Boyce and Korsmeier, 1941, and Boyce, Korsmeier, and Persing, 1942.) About the same time, it was found in Santa Barbara, Los Angeles, Orange, and San Diego counties, and several years later in Riverside County. Probably the species also occurs in New South Wales and in the Hawaiian Islands. Its place of origin is at present unaccounted for.

The citrus bud mite occurs in protected situations, as within the buds and developing blossoms and under the calyx of the fruits. The injury it causes, which differs from that caused by other species of mites that attack citrus trees, consists in deformities of the twigs, leaves, blossoms, and fruits and in multiple bud formation (figs. 213, 214). This mite has not been found on hosts other than citrus, and, of the citrus species, it markedly prefers the lemon.

*Life history.*—The eggs are white, nearly spherical, and only about 1/500 inch in diameter. They are deposited in the protected places where the mites occur, and hatch in from two to six days (the lower the temperature, the longer the incubation period). There are four developmental stages. The period from egg to adult is about ten days in summer and twenty to thirty days in winter. The full-grown mite is about 1/150 inch long, wormlike in shape, and light yellowish or pinkish in color (fig. 215).

*Control.*—The most satisfactory material for control of this mite is a spray of light-medium oil, at a dosage of 1⅔ to 2 per cent. Heavier grades of oil are not appreciably more effective; grades lighter than the light-medium, however, are less effective. The oil spray is also effective against some other pests that may be present at the same time, such as the black scale and other scale insects and the citrus red mite.

Sulfur applied as a spray may also be used. It is somewhat more effective than the oil sprays, but it may injure the tree and it is not effective on some of the other associated pests such as the citrus red mite and scale insects. Two

Fig. 213. Injury caused by the citrus bud mite, *Aceria sheldoni* (Ewing). Deformed leaves; and deformed buds and twig growth.

treatments in a year may be necessary; if so, the sulfur spray may be applied in late winter or early spring and the oil spray in the late summer or fall, a time when oil sprays are generally applied for certain other citrus pests. The sulfur spray should not be applied when temperatures are high (90° F. or

Fig. 214. Injury caused by the citrus bud mite, *Aceria sheldoni* (Ewing). Deformed lemon blossoms and young fruits; and deformed mature fruits.

above), or when high temperatures are expected within several weeks following the application. Two oil sprays, one in the spring and one in the fall, are also recommended, and this is the most generally used program.

A sulfur treatment may be either 2 gallons of lime sulfur plus 4 pounds of wettable sulfur per 100 gallons of water, or 10 pounds of wettable sulfur per 100 gallons of water. Proprietary wettable sulfur may be used, or regular 325-mesh dusting sulfur may be made wettable in the spray tank by the use

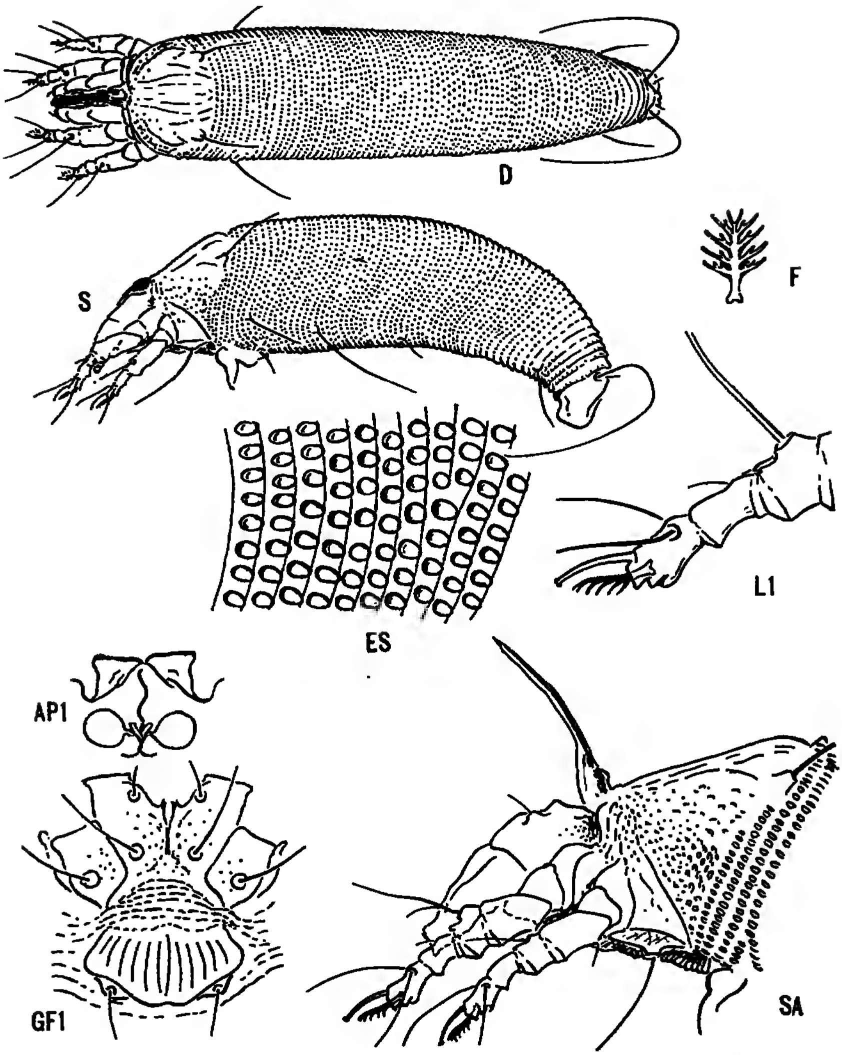


Fig. 215. Citrus bud mite, *Aceria sheldoni* (Ewing). *D*, dorsal side; *S*, left side; *ES*, detail of skin on side; *AP1*, internal female genitalia; *GF1*, female genitalia and coxae from below; *F*, featherclaw; *L1*, left foreleg; *SA*, side view of anterior section of mite. (After Keifer.)

of conventional wetting agents. Combinations of oil and sulfur are also effective against the bud mite, but these are complex and hazardous and therefore of questionable general utility.

Many new materials have been used in the studies aimed at control of this mite. The most promising is di-2-ethylhexyl phthalate, which also shows promise as a control against the citrus red mite (Jeppson, 1948).

CITRUS RED MITE, *Paratetranychus citri* (McG.)

The citrus red mite, or red spider, ranks second in importance as a citrus pest in California and third in importance in Florida; and it is almost exclusively a citrus pest. In Florida, where it is known as the purple mite, it has become a serious pest in recent years. Although it occurs in other citrus-producing countries, it is not nearly so important elsewhere as it is in the United States.

Fig. 216. Injury caused by citrus red mite, *Paratetranychus citri* (McG.). *Above,* fruit and leaf of lemon showing typical injury; *below,* normal lemon fruit and leaf; twigs defoliated owing to red spider injury on leaves.

(For general discussion of this mite see Quayle, 1912*b;* Boyce, 1936. See also pp. 667, 668, and 669 above.)

It causes a characteristic injury, represented first by pale-colored specks over the surface of the leaf and fruit (fig. 216). The specks gradually increase in number until they produce a general pale gray or silvery effect. When the mites are abundant, they also attack the tender twigs, and many eggs and cast skins may be seen on twigs as well as on leaves and fruit. Continued infestation results in leaf drop and sometimes fruit drop, particularly when the mite is active in late fall, which in California is a season of dry winds. In Florida, the greatest damage is done when severe infestations coincide with extremely dry weather.

*Life history.*—The egg of the citrus red mite differs from that of other species occurring on citrus by the presence of a vertical stalk from the top of which radiate several guy webs (fig. 217). The egg is nearly spherical, slightly flattened vertically, and when first laid is a uniform bright red color. Later the pigment gathers in specific areas, usually at one side, and finally the eyes and outline of the developing nymph can be distinguished.

The number of eggs produced by the female averages about 30, usually 2 or 3 being deposited each day. The time required for the eggs to hatch varies from eight or ten days in summer to three weeks or longer in winter.

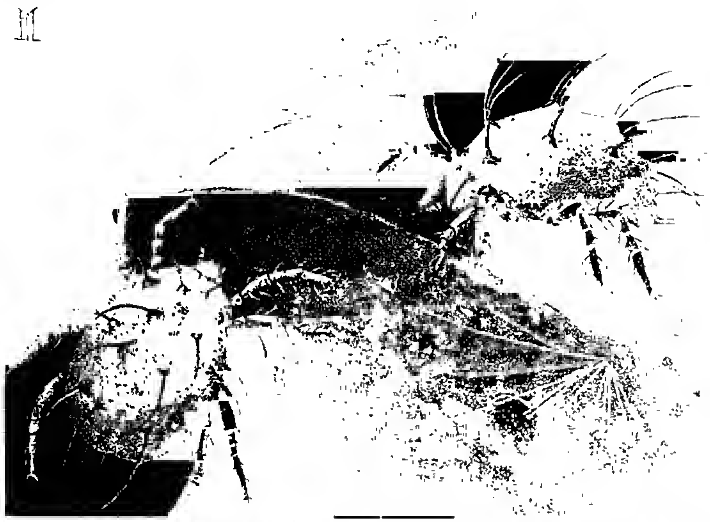

Fig. 217. Adults and egg of citrus red mite, *Paratetranychus citri* (McG.). Note vertical stalk on egg and guy threads radiating from it. (After Quayle, 1912*b* and 1932.)

The young mite is much like the adult, except that it is smaller and has but three pairs of legs, the fourth pair being acquired at the first molt. The mite begins to feed immediately after it is hatched. On the second or third day, the first molt occurs; after two or three days more, the second molt; and again after two or three days, the third and last molt.

The citrus red mite is not difficult to distinguish from the other spiders and mites found on citrus trees. It is distinctly red, commonly a dark red. The white bristles which occur on the body arise from prominent tubercles; none of the other species of mites on citrus has such tubercles. The mite ordinarily appears in greatest numbers in early spring and late fall. It is generally less abundant during the high temperatures of summer, and in the greater part of the area is not usually abundant in winter.

*Control in California.*—Sulfur, applied either as a dust or as incorporated in a spray, was formerly the material in common use for control of the citrus red mite (Quayle, 1912*b*). This material is no longer depended upon.

Oil sprays[1] are used for control of this mite, and at the same time are effective against the citrus bud mite and some of the insects. Light-medium, medium, or heavy-medium grades of oil are employed; the heavier the oil, the longer the period of effective control. Selection of the grade of oil to use depends upon the variety of citrus to be treated, the locality in which it is grown, the season of the year and, often, the species of associated scale insects present and the degree of their infestation.

It is not desirable, however, to apply oil to citrus in some localities, or at some seasons when the citrus red mite requires treatment; hence another material to use against red mite has been developed, a dusting preparation containing 1 per cent dinitro-*o*-cyclohexylphenol (DNOCHP) (Boyce, Prendergast, Kagy, and Hansen, 1939). The proprietary product, which is called DN-Dust, is applied by means of a specially designed dusting machine developed, in the main, at the University of California (Boyce and Kagy, 1941). (See figs. 218, 219.) The amount of DN-Dust used per tree varies somewhat with size and kind of tree (whether orange or lemon) and with the amount of fruit on the tree; ordinarily, from 1 to 1½ pounds is sufficient. The time to make the applications depends upon the appearance of the mites in numbers, which is generaly in spring, late summer, and fall. One treatment of DN-Dust, properly applied, usually affords satisfactory control for several months; two treatments, usually applied from ten to fourteen days apart, afford a longer period of control.

Subsequently, it has been found that the dicyclohexylamine salt of dinitro-*o*-cyclohexylphenol affords generally more satisfactory results in control of the citrus red mite than the parent compound (Boyce and Kagy, 1941; Kagy and McCall, 1941); hence the proprietary dusting preparation DN-Dust D8, containing 1.7 per cent of this salt of DNOCHP, has recently replaced the DN-Dust. The newer product is used essentially the same way as the old. Even more recently, the proprietary preparation DN-111, containing 20 per cent of the above-mentioned salt of DNOCHP, has been used as a spray, at a dosage of ¾ pound to 1 pound per 100 gallons of water.

Application of any of the above-mentioned DNOCHP materials should not be made immediately before or during periods of high temperature, because fruit and foliage may thereby be injured.

Continued research with new materials for control of the citrus red mite has resulted in developmental work, in extensive field plots, on two promising compounds, bis-(*p*-chlorophenoxy)-methane (Jeppson, 1946, 1948) and di-2-ethylhexyl phthalate (Jeppson, 1948). Bis-(*p*-chlorophenoxy)-methane, also known as K-1875, came into commercial use early in 1948. A wettable powder containing 40 per cent of this compound is marketed under the trade name "Neotran." The commercial use of di-2-ethylhexyl phthalate, also known as 899, is not contemplated at present.

"Neotran" is toxic to all stages of the citrus red mite, including eggs. Residues of this material on fruits and foliage remain toxic to the mites for a period of one to several weeks after application, and, because of this char-

[1] Oil sprays are discussed in detail on pp. 781–785.

acteristic, mites not destroyed at the time of treatment are killed as they move about over the residue. Young mites that hatch from eggs not touched by the spray are likewise killed by the residual material.

"Neotran" is applied in water suspension with the spray duster or with the conventional spray rig. When applied with the spray duster, it is used at a dosage of 7 to 10 pounds in 100 gallons of water per acre. When applied with the conventional spray rig, it is used at a dosage of 1½ pounds in 100 gallons of water, and the trees are sprayed thoroughly. This material appears to be compatible with the more important insecticides, fungicides, and mineral-element-deficiency materials commonly used on citrus. (For details see Jeppson, 1948.)

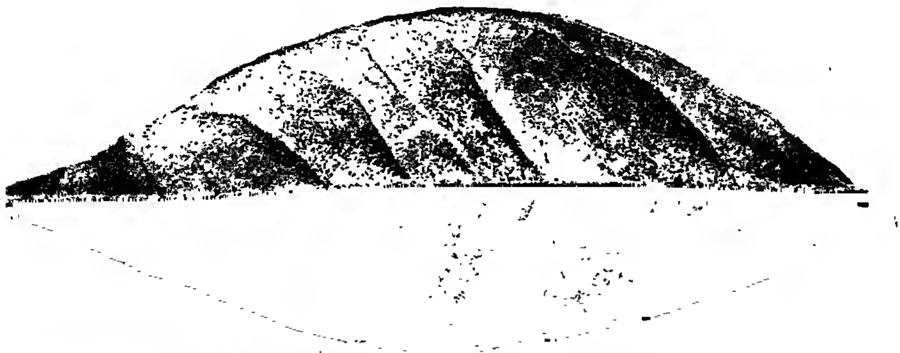

Fig. 218. Injury caused by six-spotted mite, *Tetranychus sexmaculatus* Riley. (After Quayle, 1938*b*; courtesy Comstock Pub. Co.)

*Control in Florida.*—Petroleum oil spray or DNOCHP preparations applied as spray or dust are used for control of the citrus red mite (purple mite) in Florida. The DNOCHP preparations are used with sulfur in some form for control, at one and the same time, of this mite, the rust mite, and often the six-spotted mite. The DNOCHP materials used in Florida contain the parent compound, whereas in California it is the dicyclohexylamine salt of this compound that is employed. (See section on Florida spray-and-dust schedule, p. 798.)

### Six-spotted Mite, *Tetranychus sexmaculatus* Riley

In California, the six-spotted mite is more closely limited to the coastal areas than the citrus red mite. (For general discussion of this mite see Quayle, 1912*b*.) In Florida, this species is of major importance in some years. The injury it causes is characteristic and easily distinguished from that caused by other species. The mite feeds on particular areas on the underside of the leaf, usually along the midrib or larger veins. Where a colony is active (fig. 218) there is a distinct, pale yellowish depression covered by a web that protects the mites beneath and supports the eggs, which can be seen scattered about entangled in the silk. On the upper surface of the leaf this same area

is represented by a raised part or swelling which is distinctly yellow or yellowish white and has a smooth, shiny surface. Where injury is severe, the affected areas may include the greater part of the leaf, and the leaf may become more or less distorted and misshapen and finally drop off the tree sooner than a normal leaf would do. In very heavy infestations, the mites sometimes attack the fruits of oranges and lemons. As a result of their feeding on oranges particularly, small silvery areas are conspicuous on the peel.

*Life history.*—The egg is white or yellowish white and spherical. Eggs are found only in areas where the mites feed. Each female deposits from 25 to 40 eggs in a period of ten to twenty days. Five to eight days are required for hatching in June; a longer time if temperatures are lower. The development of the species is much the same as that of the citrus red mite.

The adult of the six-spotted mite is smaller than that of the citrus red mite and is never red. The general color is light pink or greenish yellow. In some individuals a dark pigment is coalesced into six areas or spots; hence the name *sexmaculatus,* or six-spotted. The bristles are not so long as those of the citrus red mite, nor do they arise from tubercles.

*Control.*—Oil sprays are commonly used for combined control of the six-spotted mite and the citrus red mite in both Florida and California. Wettable sulfur sprays and sulfur dust, also, are effective for control of the six-spotted mite, and are used in both states. (See section on Florida spray-and-dust schedule, p. 798.) The use of sulfur for this purpose in California is limited, however, because of the "burn" that is likely to result on fruits and foliage if high temperature occurs soon after treatment.

DN-111, at ¾ pound to 1 pound per 100 gallons of water, is also used for control of the six-spotted mite in California. The new material "Neotran" shows promise in control when applied with the conventional spray rig as full-coverage spray or as dust, but not when applied with the spray duster (Jeppson, 1948).

### Texas Citrus Mite, *Anychus clarki* McG.

What was formerly thought to be the citrus red mite, *Paratetranychus citri,* in the Rio Grande Valley of Texas, has been described as another species under the name *Anychus clarki* McG. (McGregor, 1935). The Texas citrus mite, when it first hatches, is of a lemon yellow color, but later changes to a tan or greenish brown. It feeds chiefly on the upper surface of leaves, and the injury is similar to that caused by the citrus red mite.

*Life history and control.*—The development of the Texas citrus mite is more or less similar to that of the citrus red mite. Sulfur applied as dust is the principal control measure (Friend, 1946).

### Other Mites on Citrus

Some other plant-feeding mites may become locally abundant and more or less injurious to citrus. In this category are: *Tenuipalpus* species, possibly *bioculata* McG. (Lewis, 1944), *Tetranychus bimaculatus* Harvey (Quayle, 1912*b*), and *Tarsonemus bakeri* Ewing (McGregor, 1942), in California;

*Tetranychus yumensis* McG., in Arizona (McGregor, 1934) ; *Anychus orientalis* Zacher and *Epitetranychus althaea* Hanst., in Palestine (Klein, 1938).

## THRIPS

Thrips constitute a group of insects many species of which are damaging to a wide range of economically important plants. A few species are injurious to citrus trees, and more particularly so in some of the semiarid than in the

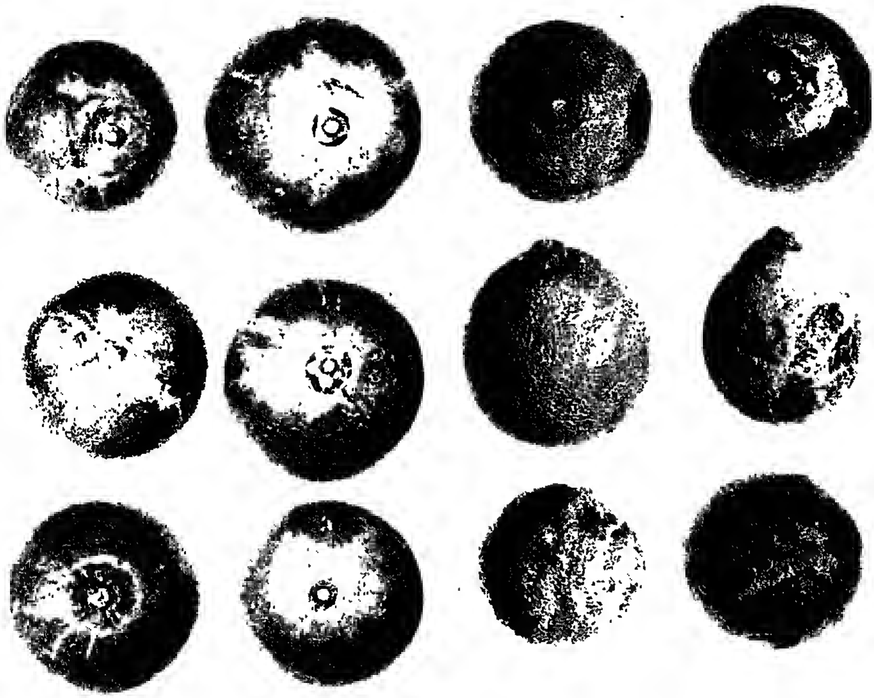

Fig. 219. Injury caused by citrus thrips, *Scirtothrips citri* (Moult.), on fruits: *left*, oranges; *right*, lemons.

humid regions. The southwestern United States, Rhodesia, and the Transvaal are areas where thrips are serious pests.

### Citrus Thrips, *Scirtothrips citri* (Moult.)

The citrus thrips is a common pest of citrus in California and Arizona. Its distribution in California indicates that it prefers the warmer and drier interior sections to the cooler and moister coastal regions. It has become increasingly important on lemons, and injurious on lemons nearer the coast (Boyce, 1938). It prefers the Washington Navel orange to the Valencia as a host, and attacks other species of citrus including the grapefruit and the tangerine. (For biological information on this thrips see Horton, 1918*b*.)

The citrus thrips obtains its food by puncturing—and possibly also by rasping—the tissues (Barnhart, 1943), which results in a characteristic scarring of the fruit. The scarring usually consists of a fairly uniform and distinct ring encircling the stem (fig. 219). When the fruit is small the ring of scarred tissue is immediately around the stem, but as the fruit grows the diameter of the ring is increased, and hence on mature fruits it may be at some distance from the stem. On severely injured lemons, particularly, the

Fig. 220. Injury caused by citrus thrips, *Scirtothrips citri* (Moult.), on lemon leaves and twigs.

scarring is not always in the form of a ring. Feeding on other parts of the fruit results in irregular and less well defined areas and may take place later in the season.

Since fruit scarring may be due to other causes, such as wind rubbing, the most nearly positive character of citrus thrips injury is the evidence of the characteristic ring about the stem.

The citrus thrips also attacks the young twigs and leaves, causing the latter to become leathery in texture, deformed, and more or less curled (fig. 220). It often feeds along an area parallel with the midrib or near the margins; pale or silvery streaks result. Injury to the leaves may occur on the spring flush of growth, but is usually more severe on the new growth in sum-

mer and early fall. The attack on the young foliage is often so severe as to check the general growth of the tree.

This thrips also attacks and severely injnres the buds, with the result that adventitious buds or a multiple bud formation appears; also twig growth of the rosette type. This type of injury, common on citrus, is more pronounced on the lemon than on other species. The citrus thrips is found in the blossoms only incidentally.

Another species, the western flower thrips, *Frankliniella moultoni* Hood, primarily a nectar feeder, commonly inhabits the blossoms, and this is the species that is commonly seen when the blossoms are shaken into the palm of the hand. The two species should not be confused. The flower thrips that are found in the blossoms are mostly winged adults that have come from various plants among or near the citrus trees. The citrus thrips is smaller, more yellowish, and generally more active than the flower thrips. The abdomen of the citrus thrips tapers abruptly and has, so to speak, a "stubby" appearance, whereas that of the flower thrips tapers gradually and is slender or cigar-shaped (fig. 221). The males of both species are considerably smaller than the females. (For details by which the citrus thrips may be distinguished from the flower thrips see Ebeling, 1933, and Woglum, 1946*e*.)

*Life history.*—The eggs are deposited within the tissues of the leaf, young fruit, and more succulent stems. The egg stage lasts through the winter, and the first larvae appear in February or March according as the season is warm earlier or later; some adults, however, may be present throughout a mild winter. The larvae are active as soon as they emerge, and feed more or less continuously except during the molting periods. The insect undergoes four molts, making two larval and two pupal stages. The first molt occurs on the leaves and fruits, and the later molts in places offering some protection, often in curled dead leaves on the ground beneath the tree. The prepupa is similar in appearance to the larva, but is somewhat paler in color and has short wing pads. In the pupa the wing pads are longer than in the prepupa, and the antennae, which project forward in all other stages, extend backward over the head and prothorax. The pupae are found on or in the ground, in dried leaves, twigs, or other debris; rarely in the upper part of the tree, and then only in a well-protected situation. Note the contrast between this species and the South African species (p. 694), in place of pupation. The life cycle of the citrus thrips is completed in about fifteen days in midsummer and in thirty days or even longer in the coolest weather, excepting the winter season, when the egg stage is prolonged. There may be a total of eight or ten generations in the course of a year.

## CONTROL IN CALIFORNIA

In California from about 1910 to 1928 lime sulfur was principally used for control of this thrips; from 1928 to 1940, sulfur dust. Hence, for about thirty years sulfur in some form was solely relied upon for control of citrus thrips. It still affords fairly satisfactory protection against fruit scarring on oranges.

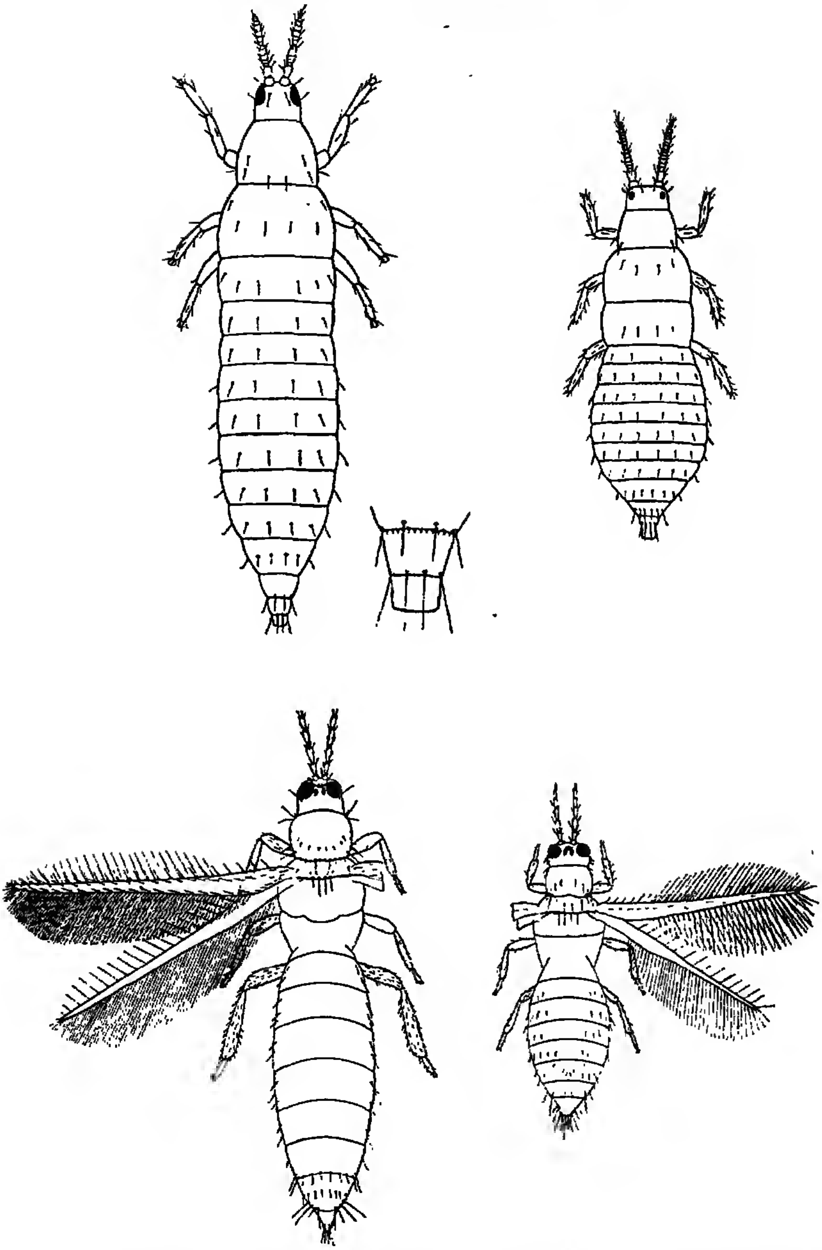

Fig. 221. Comparison of citrus thrips, *Scirtothrips citri* (Moult.), with western flower thrips, *Frankliniella moultoni* Hood. *Above*, second instar larva: *right*, citrus thrips; *left*, western flower thrips, with enlarged drawing of tip of abdomen, showing row of spines. *Below*, adult: *right*, citrus thrips; *left*, western flower thrips. (After Ebeling, 1933.)

*Sulfur dust.*—The sulfur-dusting program, for use particularly in Tulare County, California, was developed by McGregor (1930) and subsequently modified by Woglum (1945*b*). This program may be outlined as follows:

**1st Dust.—Apply 100 pounds sulfur per acre, approximately March 15 to 30.**
**2d Dust.—Apply 100 pounds sulfur per acre as soon as blossom petals start dropping.**
**3d Dust.—Apply 100 pounds sulfur per acre about two weeks after the second application.**

In southern California, the first dusting treatment may be omitted in most years because of the cool weather and the light population of thrips at that time. Because injury may result if a period of high temperature occurs, the dosage of sulfur used in the second application should be reduced to 75 pounds per acre.

Sulfur dusting is of value also in control of the citricola scale. (See section on combined treatment for thrips and citricola scale, p. 692.)

*Sulfur spray.*—For control of citrus thrips a sulfur-spray treatment applied immediately after the petals fall is somewhat more effective than the sulfur-dusting program. The formula for treatment is 2 gallons lime sulfur plus 4 pounds wettable sulfur per 100 gallons of water. It should be applied by the time the young fruits are of "pea" size in order to minimize the chances of fruit "scratching." (Woglum, 1945*b*, *c*, 1947*c*.) This treatment is also of value for control of the citricola scale.

*Tartar emetic and sugar spray.*—Commercial use of the tartar emetic and sugar treatment for control of citrus thrips was begun in 1939; and because it was strikingly effective, relatively inexpensive, and practically foolproof, it was immediately adopted and universally used. (For discussion of the early work with tartar emetic see Boyce and Persing, 1939, and Persing, Boyce, and McCarty, 1940.) In the late autumn of 1941, however, unsatisfactory results in control in lemon orchards were observed in a small locality in the San Fernando Valley, California, where much of the earlier experimental work with tartar emetic had been conducted. Early in the 1942 season, studies showed conclusively that the citrus thrips in this locality had become resistant to the treatment; also that the same species on oranges had become resistant to the treatment in several small areas in Tulare County (Boyce, Persing, and Barnhart, 1942). Since then, the resistant localities have increased in size and new ones have appeared. It is estimated at present (1948) that satisfactory results from the use of tartar emetic in control of the citrus thrips may not be obtained on more than one-fourth of the total citrus acreage where control is necessary.

The most efficient and otherwise satisfactory means of applying tartar emetic and sugar for control of citrus thrips is with the spray duster (Persing and Boyce, 1941). (See fig. 260, p. 797, below.) Using this equipment, it is necessary to apply only 20 gallons of a spray mixture composed of 7½ pounds tartar emetic plus 7½ pounds cane or beet sugar per 100 gallons of water per acre of mature trees for control of the insect on oranges and grapefruit. Hence, each acre of trees receives 1½ pounds of tartar emetic and

$1\frac{1}{2}$ pounds of sugar. However, for control in lemon orchards it is necessary to double the quantity of tartar emetic and sugar in the spray mixture, although the same gallonage, that is, 20 gallons, is applied per acre.

When tartar emetic and sugar are applied with the conventional spray rig, using either broom guns or a mechanical boom, it is necessary to use approximately 200 gallons of a spray mixture composed of 1 pound tartar emetic plus 1 pound sugar per 100 gallons of water per acre for control of citrus thrips on oranges and grapefruit. For control on lemons the concentrations of tartar emetic and sugar are doubled.

On orange and grapefruit trees, the tartar emetic and sugar treatment should be applied as soon as the petals have fallen, in order to prevent scarring of the young fruits. In some localities another treatment should be applied in August, to protect the autumn flush of new growth. On lemon trees, the treatment should be applied when the thrips population begins to build up in the spring, which is usually in May or early June. A second treatment is usually necessary in August or September.

For control of this thrips in the citrus nursery, several applications of tartar emetic and sugar are usually required. It is only necessary to cover the nursery stock uniformly with a finely divided spray. Irrespective of the method of application, approximately 4 pounds of tartar emetic and 4 pounds of sugar per acre should be used.

*Nicotine-sugar spray.*—A spray composed of nicotine and sugar has been found fairly satisfactory as a substitute for the tartar emetic and sugar treatment in areas in which the thrips are resistant (Persing, Boyce, and Barnhart, 1943). Either nicotine sulfate at a dosage of 1 quart, or the proprietary fixed nicotine-bentonite preparation, Black Leaf 155, at 7 pounds, plus 4 pounds sugar per 100 gallons, may be used. When the mixture is applied with the spray duster, approximately 100 gallons are used per acre, but when it is applied with the conventional spray rig using broom guns or a boom, approximately 300 gallons per acre are necessary. With the nicotine-sugar treatment the same quantities of materials are used on both oranges and lemons for thrips control. The time of application and the program of treatments are the same as previously indicated for tartar emetic.

*DDT (dichlorodiphenyl trichloroethane).*—Following the promising results obtained from extensive studies with DDT for control of citrus thrips in 1944 and 1945, certain suggestions were made (Boyce and Ewart, 1946) for the use of this material in central California the next year. The material was widely used in 1946 with satisfactory results in control of citrus thrips. However, in many of the orchards treated a heavy infestation of the cottony cushion scale developed, apparently because the DDT had eliminated the vedalia (Ewart and DeBach, 1947). These heavy infestations of cottony cushion scale were subsequently brought under control by the vedalia, which later became abundant as the result of colonization in, or natural immigration into, the infested orchards.

From experimental and commercial usage of DDT during 1947, further information was obtained both on the control of citrus thrips and on the

cottony cushion scale–vedalia complex. (For details, see Ewart and DeBach, 1948.) Because of incomplete information on the latter point, it is not yet possible to recommend DDT for general use in control of the citrus thrips in central California. On the basis of present information its use should not be considered if a careful survey shows that more than a trace of cottony cushion scale is present in an orchard; nor, until further information is available, should more than one application of DDT be made within a year's time; and no DDT should be applied between June 1 and August 15. With due heed to the above-mentioned conditions, the following treatments are suggested for oranges in central California.

1) For control of citrus thrips in early May to prevent fruit scarring:
   *a*) Two applications of 2 per cent DDT-sulfur dust containing at least 85 per cent sulfur at the rate of 100 pounds per acre. The first application should be made when most of the petals have fallen, and the second application two to three weeks later;

or:

   *b*) four pounds of 50 per cent DDT wettable powder suspended in 100 gallons of water per acre applied with a spray duster.
2) For control of thrips in late summer, that is, after August 15, to prevent injury to young foliage:
   *a*) eight pounds of 50 per cent DDT wettable powder suspended in 100 gallons of water per acre applied with a spray duster.

For control of citrus thrips on lemons in southern California by the use of DDT, the following suggestions are made (Ewart, 1946): for early summer, 4 pounds of 50 per cent DDT wettable powder suspended in 100 gallons of water per acre applied with a spray duster; for late summer, double the amount of DDT, that is, 8 pounds of 50 per cent DDT wettable per acre.

DDT is effective for combined control of citrus thrips and citricola scale. (See below.)

*Combined treatment for citrus thrips and citricola scale.*—From 1930 to 1940 the three-treatment sulfur-dust program for control of citrus thrips also served generally to maintain commercial control of citricola scale. Furthermore, many heavy infestations of citricola scale were brought under control by the addition of one or two more sulfur-dust treatments to the thrips-control program; that sulfur-dust treatments would control infestations of this scale had been shown by McGregor (1932). However, with increasing standards of citrus production which demand improved control of citrus thrips and citricola scale, and with the occurrence of a series of relatively cool summers which have made the sulfur-dust program less successful, this program has been much less employed.

Lime sulfur for the combined control of citrus thrips and citricola scale is most effectively applied immediately after the petals fall, in a dosage of 2 gallons lime sulfur plus 4 pounds wettable sulfur per 100 gallons water. The conventional winter spray of 4 to 6 gallons lime sulfur per 100 gallons water, applied in February and early March, cannot be generally depended upon for satisfactory control of citrus thrips.

Various formulations of DDT and programs of treatment have afforded satisfactory control of both citrus thrips and citricola scale (Boyce and Ewart, 1946; Ewart, 1946; Ewart and DeBach, 1947, 1948). In 1944 and 1945, experimental results with a program of two dust treatments in May, the dust mixture being composed of 2 per cent DDT and 90 per cent sulfur, 150 pounds per acre per application, was highly effective. However, in commercial use in 1946 this treatment was not satisfactory for control of citricola scale. The reason for the failure is not yet understood.

Treatment in late summer—that is, after the middle of August—with a spray mixture composed of 1 pound of 50 per cent DDT wettable powder and 1 gallon of kerosene per 100 gallons of water, applied with the conventional spray rig giving thorough tree coverage, has been effective in controlling both citrus thrips and citricola scale. (For details see Ewart and DeBach, 1948.) However, until more information is available concerning the effects of DDT on beneficial insects this material cannot be recommended for general use.

CONTROL IN ARIZONA

Prior to the development of the tartar emetic and sugar treatment for control of citrus thrips, sulfur dust was used to a limited extent in Arizona. The tartar emetic and sugar treatment was first employed there in 1940, and subsequently was used generally (Woglum, 1944*b*). However, only a spring treatment is usually applied. Present indications are that the citrus thrips has recently become resistant to tartar emetic in the Mesa, Yuma, and other localities (Woglum, 1947*a*; Roney and Lewis, 1948). Tartar emetic is recommended for use in those localities in which it still gives satisfactory results in control. It is used at a dosage of 3 pounds tartar emetic and 3 pounds of sugar in 25 to 50 gallons of water per acre, applied with a spray duster, or in 200 to 300 gallons of water per acre, applied with the ordinary spray rig (Roney and Lewis, 1948).

DDT is recommended for control in orchards and districts in which tartar emetic has failed. Eight pounds of 50 per cent DDT wettable powder per acre are used in 100 gallons of water when applied with a spray duster, or in 200 to 300 gallons of water when applied with the ordinary spray rig. Promising results in control have been obtained when the DDT was applied as a spray with an airplane. Although dusting with 2 per cent DDT–sulfur dust at the rate of 100 pounds per acre is effective in control, it has not been so effective as the spray treatments (Roney and Lewis, 1948).

SOUTH AFRICAN CITRUS THRIPS, *Scirtothrips aurantii* Faure

The South African citrus thrips is a common pest in Rhodesia and in parts of the Union of South Africa, particularly the Transvaal. This species, like the citrus thrips in California, is probably native to the region in which it is found and adopted citrus as a host when citrus trees were extensively planted. However, Hall (1930) believes it was introduced into Southern Rhodesia. The citrus hosts in Rhodesia, in the order of their importance, are the Washington Navel, Mediterranean Sweet, Valencia, Jaffa, DuRoi, and St. Michael.

The injury caused by the South African species is like that produced by the citrus thrips in the United States. There is, however, a secondary effect of thrips in Rhodesia (Hall, 1930) that does not occur, at least in any appreciable degree, in California; it is "tear stain," which is actually more serious than the injury caused by feeding. Tear staining is associated with rainy weather, which in Rhodesia and the Transvaal occurs in summer. Tear-stained areas on the orange as it approaches maturity are characterized by a smooth surface which gives the fruit a varnished look. In the ripe fruit such areas appear as smooth brown scars.

*Life history.*—There are important differences in the life histories of the South African species and the species in this country. Pupation of the South African citrus thrips takes place on the tree, generally on the fruit itself, whereas in California pupation of the citrus thrips takes place in debris or in cracks in the ground and rarely on the tree. All stages of the South African species may be found on the tree throughout the winter, although development is much retarded; in California, the citrus thrips usually goes through the winter in the egg stage.

*Control.*—Sulfur dust or lime-sulfur spray has been generally used for control of the South African citrus thrips. Lime sulfur at a dosage of 1 gallon per 100 gallons of water has more commonly been employed in Rhodesia and the Transvaal. Nicotine sulfate is often added to the lime-sulfur spray for the combined control of thrips and aphids. Tartar emetic and sugar is now considered most effective for control of this thrips in the western Transvaal (Smith, 1945); in certain other citrus-growing areas, however, there may be a strain of this insect which is resistant to the spray.

### GREENHOUSE THRIPS, *Heliothrips haemorrhoidalis* (Bouché)

Occasionally, the greenhouse thrips has been a pest on citrus in restricted parts of the coastal area in California, and in the last decade it has become more widely persistent on Valencia oranges in parts of San Diego and Ventura counties. Occasionally it is prevalent on grapefruit, and sometimes it is found on lemons in these areas. This thrips also occurs on citrus in Florida, Honduras, Brazil, Egypt, Palestine, Formosa, and Australia.

The effect of the feeding of this species on the fruit is different from that produced by the other two species thus far discussed. There is no deeply scarred tissue or ringed pattern of scarring around the stem end, as is characteristic of the citrus thrips. The greenhouse thrips does not usually attack the fruit until it is fairly large and often not until the yellow color begins to develop. The thrips generally begin to feed at the point of contact of fruits in clusters or where a leaf is in contact with a fruit. As a result of their feeding, the peel of the orange becomes grayish or silverish in appearance and flecked with black deposits of excrement (fig. 222). In heavy infestations the entire surface of the orange may be affected.

*Life history.*—The eggs are deposited partly or entirely within the tissues on the underside of the leaf or in the peel of the fruit. Under conditions obtaining in California the peel of the fruit is apparently more favorable

than the leaves as a food source and as a place for egg deposition. There are two larval and two pupal stages, and the complete development occurs in thirty to forty days, or longer, as the temperature varies (fig. 223). Pupation occurs unprotected on the leaves and fruit (Boyce and Mabry, 1937). There

Fig. 222. Injury caused by greenhouse thrips, *Heliothrips haemorrhoidalis* (Bouché), on orange fruit and leaf.

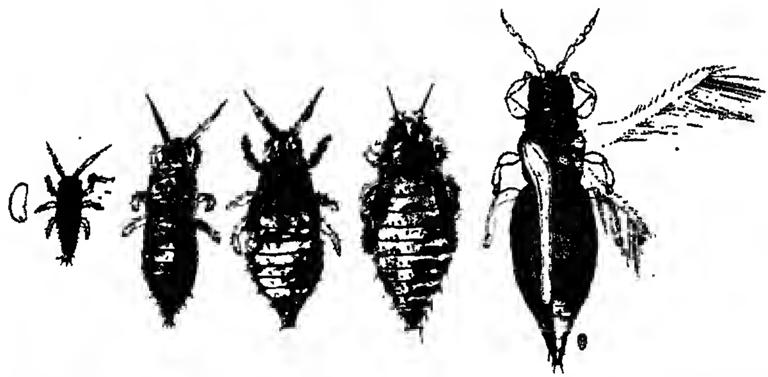

Fig. 223. Greenhouse thrips, *Heliothrips haemorrhoidalis* (Bouché). *Left to right,* egg, first-stage larva, second-stage larva, prepupa, pupa, and adult. (After Boyce and Mabry.)

are no males of this insect. The females fly rarely and feebly. (For the biology of greenhouse thrips in Palestine see Rivnay, 1934.)

*Control.*—The most satisfactory way to control this species of thrips is to use pyrethrum extract at a dosage of 1/4 to 1/2 pint (per 100 gallons) in combination with the conventional light-medium or medium grade oil spray that is used in late summer for control of scale insects and mites. In the part of San Diego County where this thrips has persisted longest it is necessary to apply a second spray of pyrethrum extract, using 3/4 pint per 100 gallons of water within twenty to thirty days after the first spray treatment. Timing

of the second treatment is important, since the application should be made after all eggs have hatched that were present when the first treatment was made, and yet before any thrips that hatched soon after the first treatment have reached maturity and deposited eggs.

DDT in various experimental formulations shows promise of results in control superior to those obtained with any other material.

Old or off-bloom Valencia oranges should be picked prior to the treatment and marketed, or thrown on the ground midway of the rows so that they will lie in the sun and any thrips present will be destroyed.

### Orchid Thrips, *Chaetoanaphothrips orchidii* (Moult.)

The orchid thrips occurs on citrus in Florida to a limited degree and may cause minor injury (Thompson, 1940). Apparently it is more common on grapefruit than on oranges. The injury somewhat resembles that caused by the greenhouse thrips. The orchid thrips in Florida seems to prefer green immature fruit, whereas the greenhouse thrips in California seems to prefer ripe or nearly ripe fruit.

*Control.*—Sulfur sprays for control of rust mite apparently keep the population of the orchid thrips at a low level (Thompson, 1940).

### Florida Flower Thrips, *Frankliniella cephalica* Craw.

The Florida flower thrips is sometimes injurious to the blossoms of oranges and grapefruit in Florida, according to Watson and Berger (1937). Their observations indicate that the insect feeds on the stamens, petals, and other flower parts, and that when feeding is extensive the fruit fails to develop or is weakened and inclined to drop early; also, that feeding on the fruit results in surface scars like those made when the wind rubs stem against fruit. Subsequently, Thompson's work (1940) strongly indicates that the activity of this thrips may not be the sole cause of the injury to citrus that formerly was attributed to it. In view of these findings he advises against attempts to control this insect.

### Western Flower Thrips, *Frankliniella moultoni* Hood

The western flower thrips are conspicuous on citrus blossoms in spring, when trees are examined for citrus thrips. They appear as adults that have come from annual or other plants on which they have passed the winter. The injury they do to the blossoms is not considered important. A generation arising from eggs deposited in the blossoms may develop on citrus as on certain deciduous trees, for example, the apricot and peach. Injury is sometimes done to grapefruit growing under desert conditions in California and Arizona. In recent years, injury has been fairly common on maturing navel oranges at Hemet and on lemons at Riverside, California, in late fall and early winter. The scarring on grapefruit caused by the flower thrips is general and irregular and may be confused with wind scarring. It is never deep and never takes the form of a distinct ring surrounding the stem, like that caused by citrus thrips.

*Control.*—No control measures have been taken against this species thus far, since they would rarely be justified.

## SCALE INSECTS

Under this heading are listed the most important citrus pests in most parts of the world. More money is spent for control of scale insects than of any other group of citrus pests. The costs of fumigation in California, Spain, Italy, Palestine, Egypt, South Africa, and Australia are chargeable entirely to control of scale insects. The species chiefly concerned are the red scales: the California red scale in California, Palestine, South Africa, and Australia; the Florida red scale in Egypt and, to some degree, in Palestine; and the Mediterranean or Spanish red scale in Spain and Italy. Besides fumigation, most of the spraying (with oil sprays) is also directed against this group.

### California Red Scale, *Aonidiella aurantii* (Mask.)

The California red scale is the chief citrus pest in California and is among the major pests in Mexico and Central America, South America, Egypt and Palestine, South Africa, Australia, and tropical Asia. It is a minor pest of citrus in many other places. Judging from its present distribution, this insect seems to thrive best in a semiarid climate. Its native home is probably in southeastern China. It was first described in 1878 from Australia, and probably was introduced into California about that time (Quayle, 1938*b*). In the past decade it has become increasingly prevalent in certain interior localities of California, as at Riverside, Redlands, and Hemet, and infestations have been found even in the Coachella Valley desert area.

The injury done by the red scale results entirely from its feeding, since neither this nor any other armored scale produces honeydew and consequently there is no medium for the growth of the sooty mold fungus. The injury caused by the feeding of armored scales differs greatly with different species and depends apparently on the amount or essential nature of a presumably toxic material injected into the plant. The red scale is virulent in this respect, and a heavy red-scale infestation quickly results in severe injury to the leaves, twigs, and branches of the citrus tree, as well as to the appearance of the fruit (figs. 224, 225).

A long list of host plants is recorded as subject to attack by this scale. Of the varieties of citrus, it appears that the citron, pummelo, and lemon are the most favorable hosts, although all varieties of citrus may be heavily infested. Other host plants often found in the vicinity of citrus are the rose, castor bean, nightshade, laurel sumac, willow, camphor, eucalyptus, carob, mulberry, avocado, and fig trees. There are also a few infestations on the English walnut. Rose hedges bordering citrus orchards are often a source of infestation.

*Life history.*—The red scale does not deposit eggs, but gives birth to young. As many as 150 or more young may be produced in two months' time by a single female (Bliss, Broadbent, and Watson, 1931). Upon emerging from beneath the female, the yellow, oval-shaped young crawl about actively for a

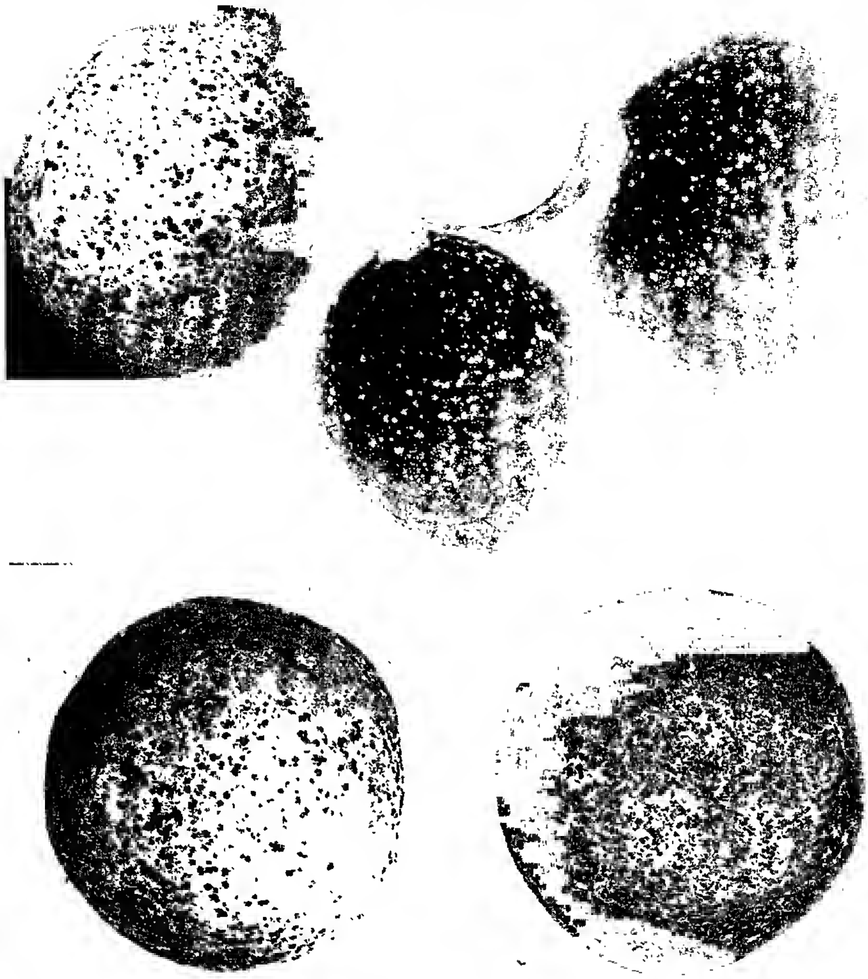

Fig. 224. California red scale, *Aonidiella aurantii* (Mask.), on lemons and grapefruits.

period of a few hours to a day or two, when they settle. The females remain settled for the rest of their existence (figs. 226, 227).

After settling, the young scale soon begins the secretion of a white, cottony covering; at this stage the young are called "white caps." The first molt occurs in seven to twenty days; the second, in twelve to twenty days more. In the course of the first molt the legs and antennae are lost and the oval crawler becomes circular. The upper part of the cast skin is incorporated in the white cottony covering, which becomes depressed, compact, and reddish in color. The upper part of the second cast skin likewise becomes incor-

Fig. 225. Young orange tree partly killed by California red scale, *Aonidiella aurantii* (Mask.) (After Quayle, 1938*b*; courtesy Comstock Pub. Co.)

porated in the scale covering, which is larger than the first but otherwise similar to it. The two cast skins may be distinguished by the circles seen in the scale covering. All this time, except during the molting period, the scale slowly revolves, its beak remaining in the tissues as a pivot (fig. 228). Thus, by means of special structures, the wax is molded and compacted in a circu-

lar form and extended beyond the insect itself to provide for future growth. Ten to twenty days after the second molt of the female, the adult male emerges and fertilization occurs.

There are thus three general stages in the development of the female red scale: the first extends from emergence to the first molt; the second, from the first to the second molt; and the third, from the second molt to and including maturity. During the molts and the period of producing young the insect

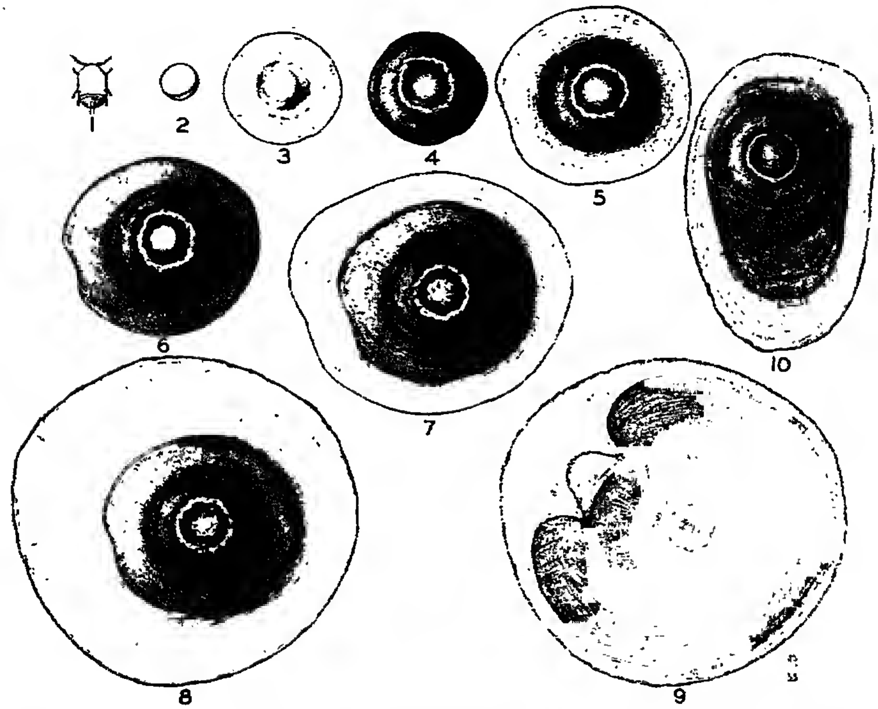


Fig. 226. California red scale, *Aonidiella aurantii* (Mask.). 1, larva or crawler; 2, white cap; 3, nipple stage; 4, just after first molt; 5, the gray margin is extended to provide for the second molt; 6, the second molt, the gray margin in 5 occupied by the second cast skin; 7, the gray margin extended after second molt; 8, the gray margin further extended and completed (the gray adult stage, when fertilization occurs); 9, the young-producing adult female; 10, the male scale covering under which the transformation to the prepupa, pupa, and winged adult occurs. Drawn to the same scale and enlarged twenty-three times, approximately. (After Quayle, 1938*b*; courtesy Comstock Pub. Co.)

and its covering are so intimately associated that one cannot lift the covering without also lifting the insect. Between the molts and until the time of fertilization the covering can readily be lifted, leaving the insect free. The female red scale grows appreciably after the second or last molt, provision being made for this growth by an expansion of the wax covering, which is indicated by a wide gray margin. The third stage may thus be further divided into two

stages: one, when the insect is free from its covering and has a wide margin of gray wax extending beyond itself; and the other, from the time of fertilization and during the period of producing young, when the covering and the scale are inseparable. Scales in the third stage are the ones that are most likely to be seen alive a week or two after fumigation.

The male insect develops differently. After the first molt, it becomes elongated and has two pairs of conspicuous purplish eyes; otherwise, its charac-

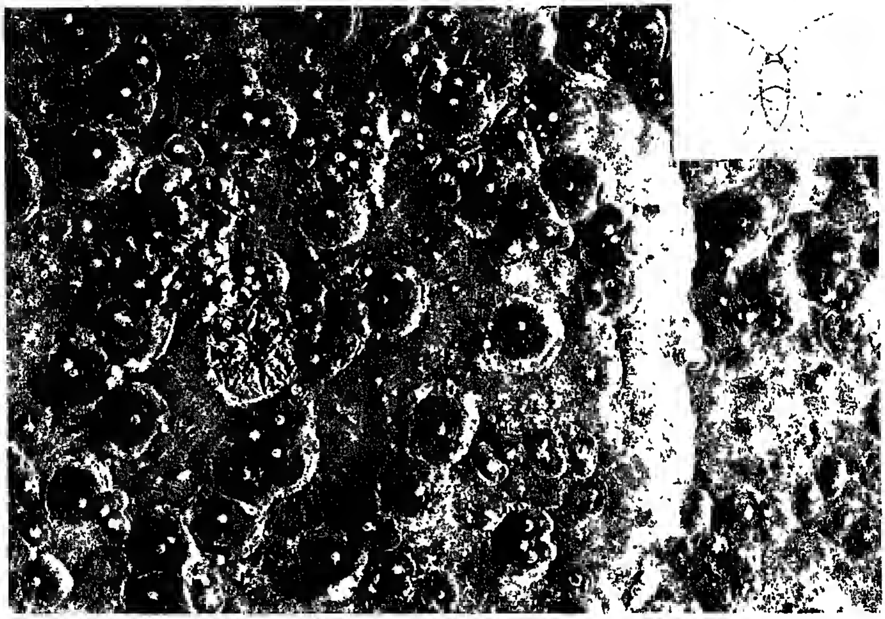

Fig. 227. California red scale, *Aonidiella aurantii* (Mask.). Mature females and adult male scale coverings, on grapefruit; *upper right*, drawing of adult male.

ters are much like those of the same stage in the female. In the second molt the prepupa is formed; in the third, the true pupa; and finally, in the fourth, the pupa is transformed into the winged adult male, which soon thereafter makes its appearance by emerging backward from beneath the scale covering.

*Dispersion.*—The red scale may be distributed over long distances on nursery stock or fruit. A spread within a community is effected by the wind, by birds and insects, and also by man in his usual cultural operations. This dispersion occurs principally while the scale is in the "crawler" stage, but it may occur at any season except in the colder weather of winter. Young red scales have been captured after having been blown by the wind a distance of 400 feet, and no doubt the wind may carry them a much greater distance. In cultural operations, twigs, leaves, and fruits infested with mature females may inadvertently be carried into uninfested orchards and become a source of crawlers, infestation following.

## CONTROL OF CALIFORNIA RED SCALE IN CALIFORNIA

Of insects that attack citrus trees this is one of the hardest to control, especially where fumigation with HCN (hydrocyanic acid) does not give satisfactory results and where spraying as a substitute has not been entirely satisfactory. Until about thirty years ago, treatment by fumigation gave good control of the red scale; but poor results were then noted in one or two limited areas (Quayle, 1938*a*), and the size and number of such areas have since increased. (For further information on the resistance of red scale to HCN fumigation see Dickson, 1941; Lindgren, 1941; Moore, 1936; Quayle, 1942; Yust *et al.*, 1942, 1943.) Except in the "resistant areas," fumigation is still a satisfactory treatment; and even there it is generally the best single treatment.

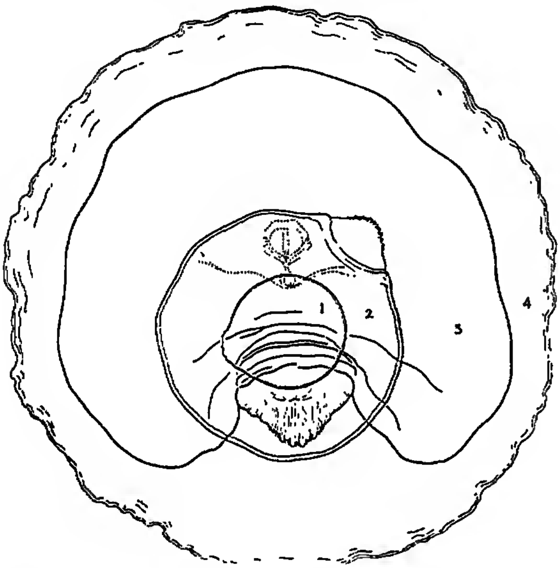


Fig. 228. California red scale, *Aonidiella aurantii* (Mask.). 1, first exuvia; 2, second exuvia; 3, the adult female; 4, the scale covering. Note that the insect has revolved during its development. (After Quayle, 1911 and 1932.)

*Red scale in resistant areas.*—The term "resistant red scale" applies to those scales which, though not immune to HCN, require such high dosages for satisfactory results by fumigation that the tree is likely to be injured; with ordinary dosages the tree is not likely to be free from scale—"free" is necessarily a relative term—even for a single year. An area in which the resistant red scale predominates is called a "resistant area." Such areas are not sharply delimited, however, because degrees of resistance vary in different orchards within the same general area and the phenomenon of resistance appears to be gradually developing in new areas.

In general it is in the higher foothill areas, particularly where lemons are grown, that growers have difficulty in obtaining satisfactory results by fumigation. These areas include Arlington and Corona in Riverside County; most of the foothill lemon area in Orange County; East Whittier, North Whittier Heights, and certain areas around Glendora, Charter Oak, Covina, and elsewhere in Los Angeles County; and parts of western San Bernardino County.

*Fumigation for red scale in resistant areas.*—Against resistant red scale as high a dosage should be used as will not injure the tree. It will vary with the locality, the season, and the variety of tree. One must bear in mind that the trees in the coastal areas are more susceptible to HCN injury than those in the interior; that the trees in all areas are usually more tolerant to HCN in the winter season; and that of the citrus-tree varieties the lemon is usually the most tolerant. Lemon trees that have been treated over a period of years with bordeaux or other spray containing copper for brown rot (*Phytophthora citrophthora*) will probably be more or less susceptible to HCN injury even in the winter season.

It is important that any treatment for red scale should be made before the infestation of the scale is heavy; otherwise it is difficult to reduce the population enough to prevent injury before the next season's treatment. Where infestations are heavy and the scales are especially difficult to control, it will probably be desirable to apply two treatments a year until the infestation is so far reduced that little injury will result. This program should not be confused with the "double fumigation" practiced against red scale where the objective is to eradicate infestations of this insect.

*Fumigation for resistant red scale on oranges.*—In winter, unfavorable weather and the presence of heaters or cover crops, or both, in the orchards do not generally permit much fumigating; nevertheless. winter fumigation should be done in orange orchards where control of the red scale has previously been found difficult. A period of cold weather, which usually occurs in the early winter, brings about a greater dormancy of the tree; consequently, at this season higher dosages of HCN can be used, and more successful control of the scales can be achieved, than at any other time of year. The favorable season usually extends from the middle of December to the end of February.

The fumigation dosages used in winter in the coastal districts are 20 to 24 cc.,[1] and in the interior districts 24 to 28 cc. of HCN.

The next best season for fumigation is midsummer and very early fall, that is, from the latter part of July until October. The orange tree is not then so susceptible to injury as it will be later—particularly in October, in most years. The midsummer season permits treating heavy infestations of red scale that would cause much more injury if allowed to continue until winter. Where the combination treatment—that is, the spray-fumigation treatment, which will be discussed later—is employed, the fumigation may follow the spray in from one to two weeks, the preferable time to spray oranges being August or early September. The summer fumigation may be begun a week or two earlier on navels than on Valencias because there is less likelihood of injury to the larger-sized fruits on the navel tree. The mature crop of Valencias should be picked before the treatment; but, admittedly, this is not always practicable. If black scale is also present, the summer treatment

[1] Twenty-four cc. is the amount of liquid HCN used for each approximate 100 cubic feet of space enclosed by a tent covering an average-sized tree. For full details see pages 776–777.

may be delayed, in some years, because the hatch of the black scale has not been sufficiently advanced.

The summer fumigation dosages in the coastal areas are from 16 to 20 cc. and, in the interior, from 20 to 24 cc. of HCN.

*Fumigation for resistant red scale on lemons.*—Resistant red scale presents a more serious problem on lemons than on oranges. A greater proportion of lemons are on the higher, warmer locations, where the build-up of the insect population is more rapid. Also, lemon fruits are present on the tree the year round, and it is on the fruit that the red scale is most likely to survive fumigation. Factors favoring the lemon include the longer winter and spring fumigation season, when the best results may be expected, and the fact that in the spray-fumigation treatment a heavier and consequently more effective type of oil may be applied to the tree.

The winter and spring fumigation season for the lemon extends from December to (usually) the end of April. In some years, treatment applied late in this season may burn the new growth, but if the young fruits are not affected the injury to growth alone is not considered serious.

The fumigation dosages in the coastal areas are 22 to 24 cc. and, in the interior, 24 to 28 cc. of HCN.

*Fumigation for nonresistant red scale.*—In areas where fumigation for the red scale need not be repeated oftener than every second year, or where a heavy infestation may be so well brought under control that no damage occurs for a single year, red scale is considered nonresistant. The fumigation treatment described for resistant red scale will apply in general for the nonresistant scale, except that (1) lower dosages may be used, (2) winter fumigation is less important, and (3) the spray-fumigation treatment need not be employed unless other pests, such as the citrus red mite and the citrus bud mite, are also present.

When it is well established that the red scale is not difficult to kill, or nonresistant, the dosage should only be reduced to the normal level for the season of year and the locality, even though a greatly reduced dosage will give a high degree of control. Because nonresistant areas cannot generally be positively and sharply defined, it is not advisable to make a drastic reduction in dosage.

For oranges in the coastal areas the dosages for the nonresistant red scale are 16 to 20 cc., and in the interior, 20 to 24 cc., of HCN. The same or slightly higher dosages may be used on lemons.

*Spraying for red scale on lemons.*—Because of the greater likelihood of adverse effects to fruits and foliage in hot weather, the spraying of lemon trees with oil is better deferred until October and November. If there are heavy infestations of red scale alone, or of red scale, citrus red mite, and citrus bud mite, earlier spraying may be necessary, followed by fumigation. Medium or heavy-medium oil is used at a dosage of 2 per cent as an emulsion or 1⅔ per cent as an emulsive.[1]

[1] The term emulsive, or emulsive spray oil, refers to a spray oil in which the emulsifier is dissolved in the oil and the preparation contains 98 or 99 per cent oil. In an emulsion the

Spraying of lemons may also be carried on in the spring, in April or May, preferably where the old crop of fruit has been picked. Usually this treatment will also control the red mite and the bud mite, which may be present, until late summer or fall.

In recent years a two-spray program, that is, a spring and a fall application of light-medium oil at 1⅔ per cent, has been satisfactorily used to control the red scale and mites, especially where the red-scale infestation was not heavy at the time the program was begun (Newcomb, 1947).

The lemons should be picked at the latest possible time before the spraying, and the next picking should be delayed as long as possible after the spraying, in order to avoid undesirable coloring of the fruit in the packing house.

*Spraying for red scale on oranges.*—Since the orange tree is more susceptible than the lemon to oil-spray injury, particularly in the interior districts, the heavier oils necessary for the control of red scale on lemons are likely to affect the orange tree adversely. For this reason a medium-grade oil is as heavy as should be used on oranges. In the interior, a light-medium is most commonly used on light to moderate infestation. The dosage of either medium or light-medium oil should be 2 per cent emulsion or 1⅔ per cent emulsive.

August and September are probably the best months for spraying oranges. In October, the trees may be more adversely affected; there may be excessive leaf drop, and reduction in the set of crop the following year. Spraying as late as November usually interferes with the proper coloring of navels or winter-ripening varieties, but spraying of Valencias may be justified. In the past few years, Washington Navel trees have been sprayed with a light-medium oil in winter and early spring after the fruit has been picked; but because the results against red scale are erratic and the trees may be damaged, this treatment should not be used except as an emergency measure.

*Spray-fumigation treatment for red scale on lemons and oranges.*—Where heavy infestations of red scale persist in spite of repeated treatments, either on lemons or on oranges, both spraying with petroleum oil and fumigating may be necessary, and the combined program can be relied upon to give best results. (For details of spray-fumigation treatment see Quayle and Ebeling, 1934.) It will at the same time control the citrus red mite and citrus bud mite, and sometimes the purple scale and black scale, also.

On lemons, a medium or heavy-medium oil, at a dosage of 2 per cent as an emulsion or 1⅔ per cent as an emulsive, is used in September, October, or November, or in April or May if the pickable fruit has been removed. (See section on spraying for red scale on lemons, above.) The fumigation may

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emulsifier is usually dissolved in water and the preparation generally contains but 80 to 90 per cent oil. Hence the difference in dosage of the two types of oil spray. The emulsions now in use are mostly "flowable," that is, they will flow from the drum container through a 1-inch faucet. The tank-mix spray, developed by Dr. R. H. Smith (1932), consisted of straight oil plus blood-albumin spreader; which, with proper spray-tank agitation, produced a quick-breaking emulsion. This represented an important contribution in the development of petroleum oil sprays and was the forerunner of the emulsive oil spray, which at present has generally replaced the tank-mix spray, and which is used at the same dosage.

follow in a week or two, may be postponed for a few months, or may precede the spraying. (See section on fumigation for resistant red scale on lemons, top of p. 704.)

On oranges, a light-medium or medium oil, at a dosage of 2 per cent as an emulsion or 1⅔ per cent as an emulsive, may be applied in August or September and followed by fumigation within a week or two or after four or five months. On Valencias in the coastal areas, the oil spray may be applied in December or January and followed by fumigation within several weeks.

*Other materials for control of red scale.*—Extensive investigational work has been conducted with extractives of rotenone-bearing plants incorporated in spray oils for control of the red scale. (For details see Ebeling *et al.*, 1944; Ebeling, 1945; and Cressman and Broadbent, 1944.) Precise laboratory studies by Lindgren *et al.* (1945) have shown that rotenone and other extractives of cubé and derris greatly enhance the effectiveness on red scale of petroleum oils of all grades from kerosene to light medium. Likewise, in many field experiments, and often in commercial usage, so-called "rotenized oils" have afforded better results in the initial kill of red scale than were obtained from the same grade and dosage of oil without rotenone. Nevertheless, the performance of rotenized oils in control of this scale insect has not been consistent enough to warrant their general recommendation.

DDT has been widely and continuously investigated for control of red scale since Lindgren *et al.* (1944) found residues of this material to be effective in preventing the settling and developing of the larvae (crawlers). In field experiments with various formulations and programs of treatment, Ebeling (1947) found that two treatments, approximately two months apart, of a formulation consisting of 3 gallons of kerosene containing 9.4 per cent technical grade DDT (by weight) and 4 ounces of blood-albumin spreader per 100 gallons of water afforded promising results in control. These treatments were also encouraging because the external or internal quality of the navel oranges was not affected by them, nor was the incidence of water spot increased. Later extensive field investigations by Carman (1948) corroborate the findings of Ebeling (1947) and supply much more information on the use of DDT in such relatively large amounts on citrus—that is, approximately 60 to 70 pounds of technical-grade DDT per acre per year. It is apparent from these studies (1) that the above-mentioned program of DDT treatments affords highly effective control of the red scale without the adverse effects on fruit quality attendant upon the use of conventional oil sprays; (2) that infestations of the citrus red mite which develop subsequent to the application of the DDT treatments are very difficult to control; and (3) that, after two successive years of treatments, the citrus trees may begin to exhibit symptoms indicative of chronic phytotoxicity. Because of these findings, and because the possible adverse effect of widespread usage of DDT on the fauna of insect parasites and predators in citrus orchards is unknown, recommendation of the use of DDT for control of red scale is not warranted.

Parathion has shown promise in early studies for control of this scale.[1]

[1] G. E. Carman, unpublished data, 1948.

*Control of California red scale elsewhere.*—HCN fumigation is generally practiced for control of this scale insect in the Mediterranean region and in South Africa and Australia. However, petroleum oil sprays are also used. In almost all other places oil sprays are relied upon for control.

### YELLOW SCALE, *Aonidiella citrina* (Coq.)

The yellow scale is associated with the California red scale in many of the more interior localities in southern California. In Tulare County it is a major pest, and during the past decade the acreage of citrus affected by it has been increasing. It is also known in Florida, Texas, Mexico, Argentina, China, and Japan. The yellow and California red scales have only recently been considered as separate species. Their morphological characters are similar, but they have long been roughly distinguishable in the field by their external appearance and habits. The yellow scale is more distinctly yellow and is found only rarely on the twigs and branches of the citrus tree. Following the studies by McKenzie (1937), they are now readily distinguished by microscopical characters (fig. 229). The host list of the yellow scale is small as compared with that of the red scale.

*Life history.*—Parallel studies on the California red scale and the yellow scale indicate no important differences in development (Quayle, 1911; Nel, 1933).

*Control.*—HCN fumigation affords most effective control. The work is generally done in August and September, and the dosage should be at least a 20 cc. schedule, and in localities where the tree will tolerate it, a 22 or 24 cc. schedule. Petroleum oil sprays are also used for control and are usually applied in August and September. Medium-grade oil is most generally employed for moderate to heavy infestations, at a dosage of 2 per cent emulsion or 1⅔ per cent emulsive.

The parasite *Comperiella bifasciata* is effective in control of yellow scale in certain localities (see chap. xii).

*Other species of "yellow scales" on citrus.*—Two species of scales closely related to the yellow scale mentioned above are recorded from citrus. They are the Oriental yellow scale, *Aonidiella orientalis* Newst., and the false yellow scale, *Aonidiella comperi* McKenzie. (For details of these species see McKenzie, 1937, and Quayle, 1938*b*.)

### FLORIDA RED SCALE, *Chrysomphalus ficus* Ashm.

The Florida red scale is an important pest of citrus in Florida, Mexico and Central America, South America, Egypt, Palestine, and in restricted areas in South Africa; it is of no importance on citrus in California. It may be found in California lath houses and greenhouses, and occasionally outdoors on certain ornamental plants in protected situations. From its limited distribution in California one may assume that it requires more humidity than the California red scale, *Aonidiella aurantii*. Florida provides conditions favorable to *Chrysomphalus ficus* and not to *A. aurantii*. In the Rio Grande Valley of Texas both species occur, but *A. aurantii* predominates; the fact

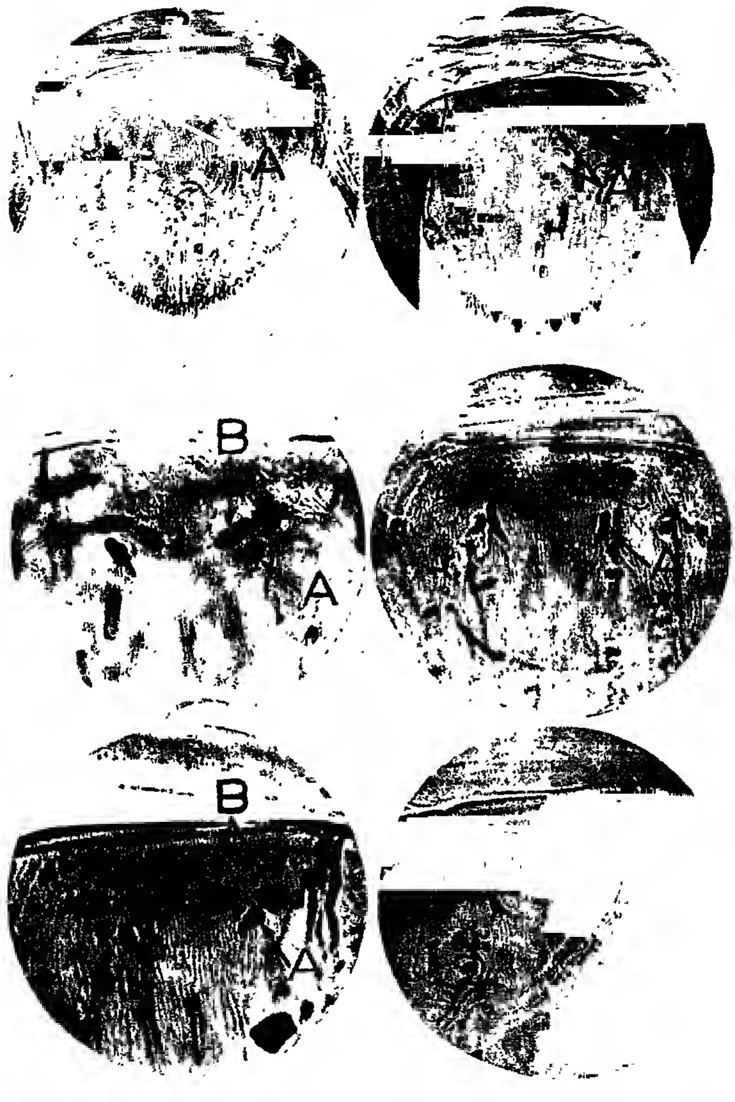


Fig. 229. Characters on the pygidium that distinguish between the California red scale, *Aonidiella aurantii* (Mask.) (*left*), and the yellow scale, *Aonidiella citrina* (Coq.) (*right*). Note particularly the absence of sclerotized structure *B* in yellow scale, its only representation in this species being branched ridges or folds. Note also that structure *A* in yellow scale is usually narrow or elongate, whereas in red scale it is, in by far the greater number of occurrences, globular. (After McKenzie.) (After Quayle, 1938*b*; courtesy Comstock Pub. Co.)

that this area is more humid than California and less so than Florida may account for the prevalence of the two species there, whereas one and not the other becomes a pest in California or Florida. The Rio Grande Valley has a relatively arid climate, but apparently humidity enough to permit *C. ficus* to thrive. Lower Egypt, where *C. ficus* predominates, may have still greater humidity. Hall (1924) states that this species is not widely or firmly established in Upper Egypt, a more arid region. The prevalence of *C. ficus* in the Delta of Egypt may be explained by the humidity supplied by irrigation, not only in the citrus orchards, but in the surrounding cotton and corn fields as well. In South Africa *A. aurantii* greatly predominates over *C. ficus* as a citrus pest, although *C. ficus* occurs there in certain restricted districts—in the Transvaal and Natal—where summer rainfall occurs.

The distribution of these two species may not depend upon the prevalence of a humid or an arid climate, but simply upon a difference in the degree of humidity. Moreover, intelligent discussion of the influence of climate on pests is limited to established conditions where there has been abundant opportunity for the spread of the pests.

The Florida red scale is dark brown to purplish black, with a lighter center. The color accounts for the common name "black scale" in Egypt, and "purple scale," also "circular purple scale," in South Africa. The list of food plants of this insect is extensive.

*Life history.*—Unlike *Aonidiella aurantii,* this species produces eggs, which are of a yellow color, and these hatch into motile young or crawlers, which thereafter follow a development similar in all important respects to that of *A. aurantii* (p. 697). One of the minor differences, however, is that the scale covering of the female of *C. ficus* can always be readily removed from the insect beneath, whereas the scale covering of the female of *A. aurantii* cannot be separated from the insect during the molting periods, nor after the beginning of reproduction.

*Control.*—In Florida and other Gulf states, spraying with petroleum oil is the chief method of control because the prevailing conditions are not suitable for fumigation. (See Florida spray-and-dust schedule, p. 799.) In Egypt, Palestine, and South Africa, fumigation is generally practiced; however, oil sprays are also used there, and they are solely relied upon for control of this scale in Mexico and in Central and South America. (For discussion of entomogenous fungi see chap. xiii.)

MEDITERRANEAN RED SCALE, *Chrysomphalus dictyospermi* (Morg.)

The Mediterranean red scale is probably the insect most destructive of citrus in Spain, Italy, and northern Africa. It does not occur as a citrus pest in the eastern Mediterranean Basin (Quayle, 1938*b*). In many parts of South America it is commonly found on citrus.

It is generally distributed in Florida, but does little damage to citrus there. In California, it occurs in greenhouses and lath houses on ornamental plants and to a limited degree on the avocado. A restricted infestation, which has since been eradicated, occurred in citrus orchards in Ventura County about

ten years ago. Since it occurs as a pest in Spain and Italy, where climatic conditions are closely similar to those in California, it should be considered a potential pest of citrus here.

This species, like the yellow scale, attacks the leaves and fruit; but because it does not infest the twigs and branches so severely, the injury it causes is not so great nor so rapid as the damage done by the California red scale. It also resembles the yellow scale in appearance. Its scale covering, like that of the Florida red scale, can be readily separated from the insect itself at any time; and, like the Florida red scale, it deposits eggs.

*Control.*—In Spain and Italy, fumigation and oil sprays have been extensively employed. In the other countries where control measures are used, oil sprays are relied upon.

### Rufous Scale, *Selenaspidus articulatus* (Morg.)

The rufous scale, sometimes called the West Indian red scale, is injurious to citrus in the West Indies, Mexico, Central America, and Peru. It infests limes in southern Florida. The female scale is nearly circular, flat, and yellowish brown in color. In heavy infestations these insects encrust the branches, leaves, and fruits. Oil sprays afford satisfactory control.

### Oleander or Ivy Scale, *Aspidiotus hederae* (Vallot)

The oleander or ivy scale is an omnivorous scale that occurs widely in the citrus-growing regions of the world. The female is circular, of a grayish color, and much less convex than the greedy scale, which is sometimes associated with it. In California and in Spain this insect occasionally occurs in large numbers on old oranges that remain on the trees after the regular harvest season. It is often damaging to lemons in Sicily, where it occurs in numbers so large as to distort the shape of the lemon fruits. It also delays the coloring; infested fruits may be distinguished even from a distance by blotches of yellow and green. Little or no control is practiced against this insect.

### Greedy Scale, *Aspidiotus camelliae* Sign.

Greedy scale is found on a wide range of host plants throughout the world. It is fairly common on citrus, especially on old oranges that have remained on the tree from the previous year, or on the older tree-ripe lemons, and it also occurs on the twigs. It is of little consequence, however, as a pest. It may be distinguished from the red or yellow scales by its light gray color and much greater convexity. Control is generally unnecessary.

### Camphor Scale, *Pseudaonidia duplex* (Ckll.)

The camphor scale was found in Louisiana in 1920, apparently having been introduced from Japan, where it occurs on citrus. It has also been recorded from Alabama, Mississippi, and Texas. (For general treatment of this insect see Cressman and Plank, 1935.) Although nearly two hundred hosts have been found in Louisiana, this scale is of most importance as a pest on the camphor tree and the Satsuma orange. The insect attacks all parts

of the latter host plant. The younger twigs may be killed. The fruits become heavily infested, and their market value is thereby reduced.

The adult female scale is nearly circular, distinctly arched, and blackish brown in color, with the exuviae subcentral and of an orange color.

Oil sprays afford satisfactory control on established citrus trees, and HCN fumigation is effective for control on citrus nursery stock.

PURPLE SCALE, *Lepidosaphes beckii* (Newm.)

The purple scale is first in importance as a citrus pest in Florida and parts of South America and is among the first three or four most important pests of citrus in California, Mexico and Central America, Spain, Italy, Egypt, Palestine, South Africa, and tropical Asia. (For general treatment of this insect see Quayle, 1912*a*, 1938*b*; Watson and Berger, 1937.) Although it has a wider climatic range than any of the scales thus far discussed, in California it is limited to the more humid areas along the coast. It does not occur in the interior sections of southern California, although contiguous citrus plantings connect this area with the coastal one and the insect has not lacked opportunity to spread in the sixty years of its occurrence in the State. Thus far, it has not occurred in Riverside and San Bernardino counties; notwithstanding that contiguous citrus plantings extend through Los Angeles and San Bernardino counties, its presence ceases before the line dividing those two counties is reached. It occurs at the westerly end of Santa Ana Canyon, but not in the Corona and Riverside districts to the east. In the canyon, there is something of a break in the citrus plantings, but because traffic through the canyon is heavy, it would not be unreasonable to suppose that the purple scale might be carried many times into the more eastern section of Riverside County. However, a series of years favorable to the insect might result in its establishment farther inland than at present. It does not occur as a citrus pest in the San Joaquin and Sacramento valleys of California. In South Africa it does not occur in the citrus-growing areas of the interior, but becomes important as a pest in the coastal areas.

The purple scale attacks all parts of the citrus tree: leaves, twigs, branches, and fruit (fig. 230); but in California, at least, it exhibits a strong preference for the north side of the tree and often only the lower or interior part, a rather large area of which may be killed. The presence of the scales on the fruit mars its appearance. They are removed with difficulty by washing and brushing in the packing house.

This insect occurs on a wide variety of hosts in many parts of the world.

*Life history.*—The oval, white eggs of the purple scale are readily seen when one turns the adult female over (fig. 231); their number varies from 40 to 80. They are deposited in the course of four to six weeks, those at the posterior or broad end of the scales being the oldest. The space beneath the covering at first occupied by the adult female is gradually filled with eggs as the parent contracts in size toward the anterior end, during egg production.

The white, oval larva crawls about for a few hours or a day or two, and then settles and becomes fixed in position. Very soon, from just under the

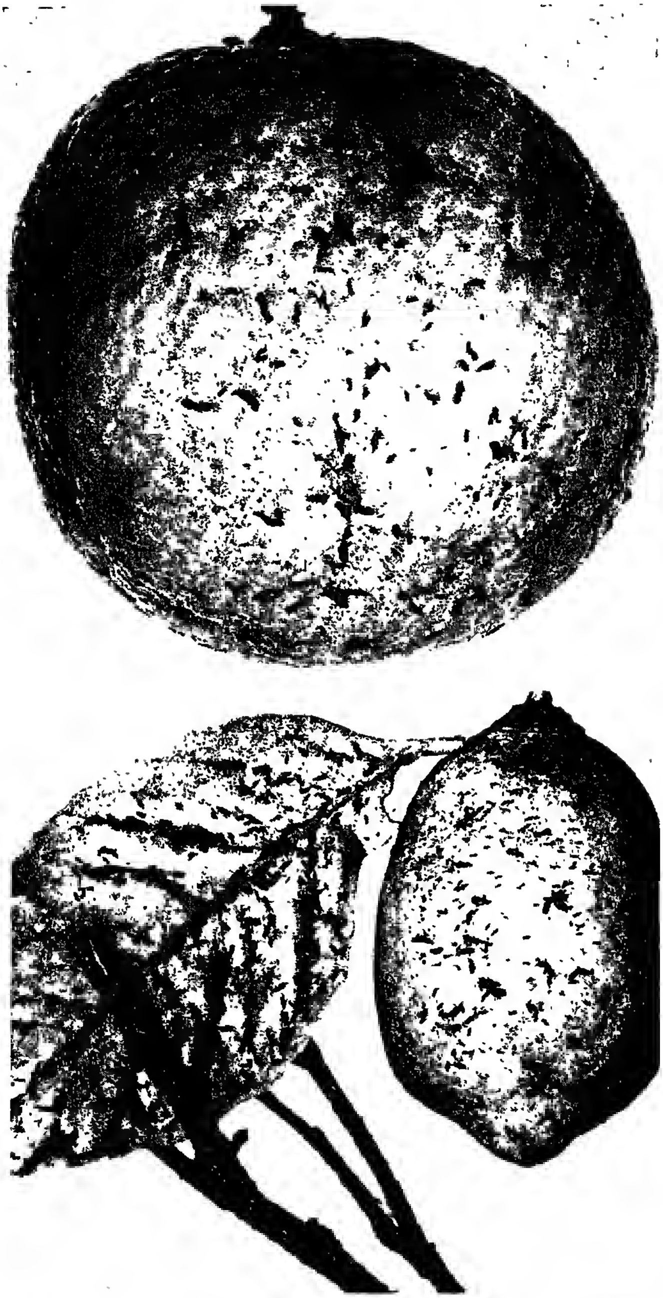

Fig. 230. Purple scale, *Lepidosaphes beckii* (Newm.), on orange and on lemon twig, leaf, and fruit.

margin at the anterior end, two long, coarse, entangling threads are secreted, which extend entirely over and around the insect (see fig. 230). These threads remain until the insect is about half grown, probably serving as a protection while the more permanent covering is being formed. When large numbers of the scale have recently hatched, the threads give a general fuzzy effect; and the fuzziness serves as a guide in applying control measures, since its presence indicates an optimum condition for the best results from both fumigation and spraying.

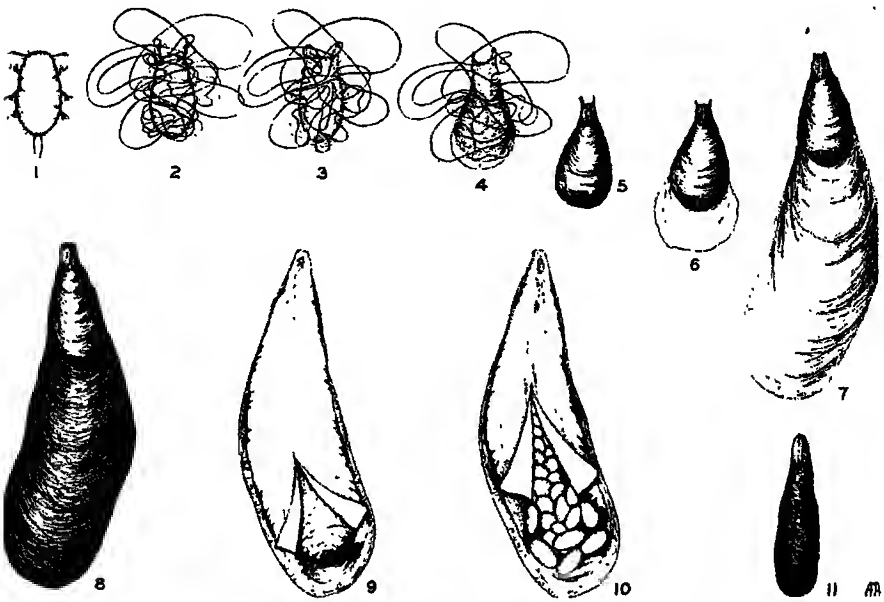

Fig. 231. Purple scale, *Lepidosaphes beckii* (Newm.). 1, larva or crawler; 2, secretion of two coarse entangling threads; 3, secretion of fine cottony threads, the beginning of the scale covering; 4, just after the first molt, with the first exuvia shown; 5, the second molt, and the first and second exuvia shown; 6, secretion of scale covering seen extending beyond the second exuvia; 7 and 8, adult female; 9, female inverted, the lower scale covering drawn aside to show the insect itself; 10, female inverted, showing eggs in the place formerly occupied by the body; 11, scale covering of adult male. All × 17. (After Quayle, 1938*b*; courtesy Comstock Pub. Co.)

After the two long protecting threads are formed, the insect begins the secretion of the permanent scale covering—a secretion of much finer threads, which cover the insect more completely. The female undergoes two molts at intervals of about three to four weeks. The male, like that of the red scale, passes through four molts, with a prepupal and a pupal stage, before issuing as a winged adult about sixty days from hatching. The female, seventy or seventy-five days after hatching, begins to deposit eggs and continues to do so for three or four weeks. In most of the areas infested by purple scale there are two or three generations a year.

*Control.*—In California the optimum time for treatment is summer and fall. Although the occurrence of the younger and more susceptible stages of this scale is less uniform than with respect to the black scale, it is somewhat more uniform with respect to the red; the time of hatch of the purple scale is therefore one of the factors that influence the time of treatment, which may be as early as mid-July and as late as November, although August and September are usually the preferred months. Since the black scale is often associated with the purple, the time of treatment may be influenced also by the hatch of the black scale. Winter fumigation has not proved satisfactory for control of the purple scale, perhaps because it is difficult to kill the eggs in the colder weather. The best single treatment for purple scale is fumigation with a dosage of 18 to 20 cc. of HCN, if such a dosage may be used safely, although oil sprays are generally used with success. If infestations are heavy, it may be necessary to spray also with light-medium or medium oil at 2 per cent as an emulsion or 1⅔ per cent as an emulsive, before or after fumigation. Usually, the purple scale is not so generally distributed in a grove as some of the other scales, and it is often desirable to "double treat" the heavily infested trees. When a grove is sprayed generally, the trees heavily infested with the purple scale may be spot-fumigated, also; and when the grove is fumigated generally, the trees with purple scale may be spot-sprayed.

DDT (technical grade) incorporated in kerosene, and also in mineral seal grade petroleum oil, is highly effective in control of the purple scale (Lindgren *et al.*, 1946; and Carman, unpublished, 1948). However, insufficient information is available concerning various other aspects of the use of DDT on citrus in those areas in which the purple scale occurs to justify its recommendation. (See discussion of DDT in connection with control of California red scale, p. 706.)

Parathion has shown promise in preliminary studies for control of the purple scale.[1]

Oil sprays are universally used for control of the purple scale in Florida (see section on Florida spray-and-dust schedule, p. 798), Mexico, and Central and South America. They are used to some degree in other countries, but fumigation is most generally used in the Mediterranean countries and in South Africa. (For discussion of entomogenous fungi see chap. xiii.)

### Glover's Scale, *Lepidosaphes gloverii* (Pack.)

The Glover's scale, or long scale, is similar to the purple scale in color and shape, but is much narrower and less curved (fig. 232) (Quayle, 1938*b*). It is associated with the purple scale in Florida, Mexico and Central America, South America, and Spain, and in Japan it is a more important pest than the purple scale. It also occurs in South Africa and Australia. In California it occurs on citrus in a limited region in Orange County, where it is an important pest.

Control is essentially the same as that for the purple scale.

[1] G. E. Carman, unpublished data, 1948.

BLACK PARLATORIA SCALE, *Parlatoria zizyphus* (Lucas)

*Parlatoria zizyphus* (Lucas) is common in Spain, Algeria, Tunis, and Morocco (Quayle, 1914); it also occurs in Sicily, Crete, Italy, Cyprus, Argentina, tropical Asia, and China. It is prevalent on the leaves, twigs, and fruits (fig. 233), and because it adheres firmly to the fruit and is not easily removed by rubbing, it occurs commonly on fruits in the markets. The female scale

Fig. 232. Glover's scale, *Lepidosaphes gloverii* (Pack.), on orange. (Photo courtesy H. J. Quayle.)

covering is black, rectangular, and with a fluted surface; the male scale covering is white except for the larval skin at the anterior end, which is black.

Treatment for control of this insect is not generally practiced, although both fumigation and oil sprays are effective.

CHAFF SCALE, *Parlatoria pergandii* Comst.

The chaff scale is one of the important citrus pests of Japan, Palestine, and Egypt, and is of some importance in Florida and other Gulf states. In Japan, it is particularly abundant on the navel orange on the island of Shikoku and on the Unshu orange in the vicinity of Osaki (Clausen, 1927). Besides being a major pest in Palestine and Egypt, it is widely distributed in other countries around the Mediterranean Sea, as well as in the Azores, Bermudas, and islands of the West Indies, and in Mexico, Central America, and parts of South America. Because the scales are gray or brownish gray and

overlap one another on the branches, the affected tree has an appearance of being covered with chaff; hence the common name of the insect (Watson and Berger, 1937).

Oil sprays and fumigation, where practiced, afford effective control.

### Snow Scale, *Chionaspis citri* Comst.

The snow scale, sometimes called the orange chionaspis, and in Australia the white louse, is considered the third most important pest of citrus in that country. It is also of importance in tropical Asia, South America, Mexico,

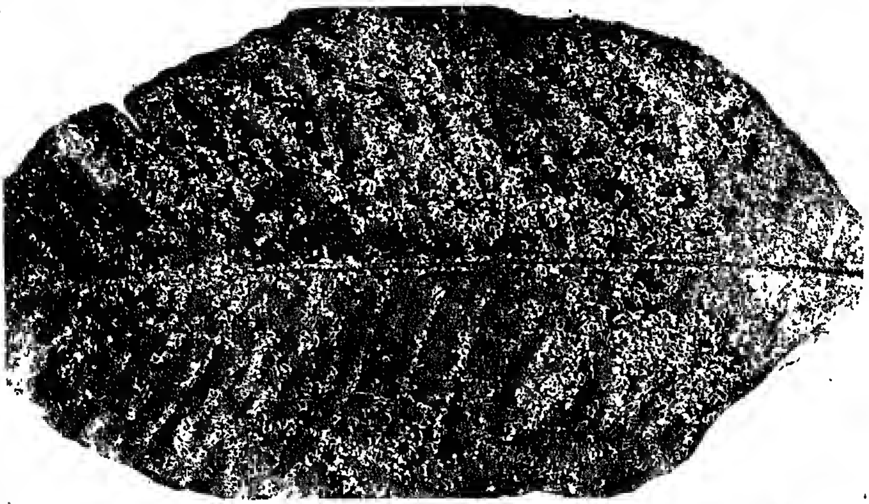

Fig. 233. Black parlatoria scale, *Parlatoria zizyphus* (Lucas), on orange leaf. (Photo courtesy H. J. Quayle.)

and to a very limited degree in Florida and other citrus-growing regions of the Gulf states.

The male snow scale is snow-white in color and has a prominent longitudinal center ridge and a fainter one on either side. The female, dark brown with a lighter margin, resembles the color of the bark of the tree. In shape the snow scale resembles somewhat the purple scale, but it is much broader. It has a prominent longitudinal ridge, which, with the color, readily distinguishes it.

The snow scale infests all parts of the tree, but is most abundant on the trunk and main branches. As a result of infestation the bark becomes hardened and soon splits (Summerville, 1935*b*).

*Control.*—Lime sulfur at a dosage of 8 per cent applied in late winter is the most satisfactory measure of control in Australia. Fumigation is effective there, but oil sprays are not as effective as lime sulfur or fumigation. However, in Florida and in Latin America, except Colombia, oil sprays are satisfactorily used. In Colombia, lime sulfur at a dosage of 4 per cent is considered more effective than oil.

### Yanone Scale, *Prontaspis yanonensis* (Kuw.)

The yanone scale is the most injurious citrus pest in Japan. It is also reported from China, which is considered its native home. The female scales attack chiefly the smaller branches and twigs, but also occur in great numbers on the fruit. As a result of heavy infestations the trees are severely injured and may be killed. Infestations are conspicuous because of the large masses of white male cocoons. There are three generations in a year (Clausen, 1927).

This scale was formerly known in Japan as *Chionaspis citri*, or the true orange chionaspis, or the snow scale that occurs in the southern United States, Latin America, and Australia. Its species name was changed to *yanonensis* by Kuwana, who soon thereafter placed it in the genus *Prontaspis*.

Few, if any, control measures against citrus insects in Japan have been practicable. Fumigation is practiced in a limited way, and some work is done with kerosene emulsion, hand pumps being used (Clausen, 1927).

### Aspidistra Scale, *Pinnaspis aspidistrae* (Sign.)

The aspidistra scale is a pest on citrus in Japan, and is also important in Colombia, Brazil, and Argentina. It is widespread in distribution throughout the world, and occurs on many hosts. The female scale is pale brown in color, flat, and roughly pear-shaped (Quayle, 1938*b*).

*Control.*—No control is practiced in Japan. In South America, oil spray is used when necessary.

### Black Scale, *Saissetia oleae* (Bern.)

The black scale is one of the most widely distributed of all of the insects attacking citrus trees. (For detailed treatment of this insect see Quayle and Rust, 1911; Quayle, 1938*b*.) It occurs in all the important citrus-growing regions of the world, but varies greatly in its status as a pest, being most important in California and in Spain, and of some importance in Italy and North Africa. Until about 1940 the black scale was the most important pest of citrus in California. Its relatively low status at present is apparently due to effective control by parasites, together with rigorous treatments necessitated by the increased importance of California red scale in some localities and of citrus bud mite in others. It is not a pest in Florida, probably because of high humidity. It is not an important pest in South Africa; yet in parts of South Africa the climatic conditions are similar to those in California, where the black scale thrives on citrus. The activities of parasites may have held down its numbers in South Africa. In Australia, it is sometimes an important citrus pest, particularly in the districts nearer the coast. Much of the citrus in Australia is grown under climatic conditions similar to those of the most interior localities in California, which are unfavorable to this insect.

The black scale does not thrive on citrus under a combination of high temperatures and dryness, as is strikingly shown by the fact that it is not a pest in such interior regions of California as the Sacramento, San Joaquin,

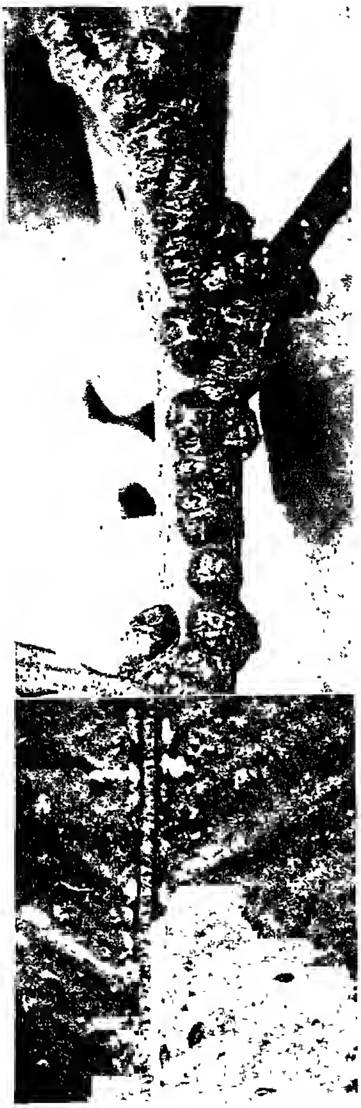

Fig. 234. Black scale. *Saissetia oleae* (Bern.). *Above*, mature females on orange twig; *below*, newly hatched scale on under side of orange leaf. (Photo courtesy H. J. Quayle.)

Coachella, and Imperial valleys; nor under conditions of high humidity, as is indicated by its innocuousness in Florida (Watson and Berger, 1937), although it is generally distributed there.

Many plants, both ornamental and economic, are hosts to this insect. Some of the preferred host plants—in fact, more preferred than citrus—occur in close association with citrus plantings in southern California and elsewhere. Prominent among these are pepper trees, often used as border trees, and olives, which may be border trees or adjacent plantings.

*Injury.*—The injury done by the black scale is referable to the extraction of the juices of the plant and to the sooty mold fungus, *Meliola camelliae* Catt., which grows in the excretion, or honeydew, of the insect. The feeding of the young scales on the leaves and twigs reduces the vigor of the tree, and when the mature scales mass themselves on the twigs and branches the injury proceeds until those parts, if not actually killed, are unable to support the crop of fruit. The coating of sooty mold fungus interferes with the normal functions of the leaves and renders the fruit unmarketable unless the sooty coating is removed by washing.

*Life history.*—The mature female scale is dark brown to jet black in color, and there are ridges on its back which roughly form the letter H (fig. 234). The eggs, which are pearly white to pink, changing color as they age, may be seen upon lifting the mature female scale. The number will range from a few hundred to 4,000, the average being about 2,000. The light-brown young larvae appear after the eggs have been deposited fifteen or twenty days, and crawl about, often for a day or two, before settling. The first molt occurs from 1 month to 6 weeks after hatching, and the second molt from 2½ to 3 months after hatching.

Before the first molt, there is no distinguishable difference between the male and female. After the first molt, the male becomes much more elongate,

and its eyes become visible. It will be noted, with respect to the armored scales such as the California red and purple scales, that the covering under which the male transforms is secreted from the beginning. The development of the male through the delicate prepupal and pupal stages could not very well take place without some protection also; and since the black scale has no armor, in the second stage of the male a puparium is formed—a transparent covering, glassy in appearance—under which the transformations to the prepupal, pupal, and adult stages take place. The male of the black scale is found only occasionally. Reproduction ordinarily occurs without fertilization.

### CONTROL OF BLACK SCALE IN CALIFORNIA

Since 1940, infestations of black scale have been lighter than ever before, chiefly because imported parasites (Smith, 1942) have been effective checks, and because of the rigorous pest-control measures necessitated by the increase of California red scale in many districts, and of the citrus bud mite in others.

Black scale is controlled mainly by fumigation or spraying. Choice of treatment and time of application are influenced (1) by the degree of the insect's resistance, in some areas, to HCN, and (2) by its frequency of reproduction: one generation in a year, or two. The black scale in the interior areas has one generation a year; that in the coastal areas may have two, overlapping more or less. Treatment is most effectively applied when the younger or susceptible stages of the insect are predominant. In the warmer, interior areas, the younger stages are present from midsummer through autumn, and the time to begin treatment is when most of the eggs have hatched, that is, in late July or early August, and when the fruits (oranges) are large enough to tolerate the applications. Treatments may then be given at any time in the succeeding two or three months. In the coastal areas, the younger stages may be present in midsummer and again in midwinter.

*Fumigation for black scale.*—In parts of eastern Los Angeles and western San Bernardino counties, the black scale has been difficult to kill by fumigation (Quayle, 1938*a*). (For details of fumigation see p. 771.) Some indication of fumigation tolerance seems to be appearing in this scale in a few other restricted areas. Except in these areas, fumigation is a satisfactory method of control and may be relied upon to clear up a heavy infestation and, usually, make further treatment for this particular insect unnecessary for two or three years.

The dosage in the coastal areas is from 16 to 18 cc., and in the interior from 18 to 22 cc., of HCN. The presence of red or purple scales will make it desirable to raise these dosages somewhat, particularly on lemons. Fumigation should be done as soon as possible after the appearance of the young or most susceptible stage of the insect, especially of Valencia trees that have the old fruit still on them. As previously stated, there are two seasons for treating black scale in the coastal areas, where it has two broods a year.

*Spraying for black scale.*—The black scale, which lacks the firm waxy covering or armor that protects such scales as the red, yellow, and purple, may be satisfactorily controlled by oil sprays. It yields to oil sprays of the

lighter grades, which are not so detrimental to the tree. (For details of oil sprays see p. 781.) These sprays are also valuable for the control of the citrus red mite and citrus bud mite, which may be present in association with the black scale. A light-medium oil is used at a strength of 2 per cent as an emulsion or of 1⅔ per cent as an emulsive.

The most favorable season for spraying oranges is usually from the middle of July to the end of September. In the coastal districts, where the black scale is double-brooded, it is usually "out of condition" for effective control by middle or late August. However, the next generation is usually "in condition" for treatment in December and January. As a general practice it is not advisable to use oil spray over the ripe crop of Valencias. Lemons may be sprayed at any season when the scale is in satisfactory condition for effective control. Lemons should be "closely" picked before spraying with oil, and the next "pick" should be delayed as long as possible after the spray application. Where red scale is present, a medium oil may be used in both intermediate and coastal districts on oranges as well as on lemons; but because of adverse tree reaction the use of this grade of oil on oranges is not considered generally desirable in the interior districts. For lemons, a heavy-medium or even a heavy oil may be required, under certain conditions. In the intermediate area of eastern Los Angeles and western San Bernardino counties the water spot on navel oranges is greatly accentuated by oil spray (Ebeling and Klotz, 1936).

The incorporation of rotenone in oil sprays not only makes practicable a reduced dosage of oil for control of the black scale, but also assures killing a greater proportion of larger-sized black scale than can be done with a full dosage of oil. Rotenized oil sprays have been used in the areas toward the coast where the black scale has two generations a year, usually with some overlapping. These sprays ordinarily consist of 0.75 to 1 per cent light-medium oil containing approximately 0.05 per cent rotenone derived from derris or cubé extractives or from powdered rotenone-bearing roots (Boyce *et al.*, 1940).

*Sulfur dusting for black scale.*—In some citrus-growing areas of California sulfur dusting for the control of citrus thrips keeps the black scale population so low that the interval between the more effective treatments of fumigating or spraying may be prolonged. Sulfur also evens the hatch by killing the young that appear early and thus makes more effective the later treatment by fumigation or spraying. Furthermore, it tends to free the tree from sooty mold fungus, which grows in the honeydew given off by the black scale.

Sulfur dusting should be avoided in hot weather—that is, when the temperature is at 90° F. or higher,—in order to lessen the probabilities of injury, particularly to fruit. It should not be used later than June; in fact, it should be used with caution even after March. Since black scale may continue hatching until after midsummer, sulfur applications cannot be continued long enough to be relied upon as a general method of control. In the cooler citrus-growing areas, sulfur is of no value in control of the scale; its use only prevents development of the sooty mold fungus.

*Other materials for black scale.*—DDT and parathion both show promise in preliminary studies for control of the black scale.[1]

*Control of black scale in other countries.*—Either fumigation or oil sprays are used for control of this insect in Spain. Italy, North Africa, and Australia.

### HEMISPHERICAL SCALE, *Saissetia hemisphaerica* (Targ.)

The hemispherical scale, widely distributed throughout the world, attacks citrus in many localities but is of little importance anywhere as a pest. In California it is found most commonly in the coastal sections of Santa Barbara and San Diego counties. It is a scale that is easily distinguished by its hemispherical shape, brown color, smooth shiny surface, flare at the margin, and lack of the H-shaped mark which occurs on the black scale, its nearest ally on citrus. When control is necessary, oil sprays give satisfactory results.

### CITRICOLA SCALE, *Coccus pseudomagnoliarum* (Kuw.)

As a citrus pest, the citricola scale is at present limited to California. Clausen (1927) reports that this insect is widespread in Japan but is of no consequence as a citrus pest there. In the San Joaquin and Sacramento valleys of California, it is more important than any other scale insect on citrus. In southern California, it occurs only in the more inland localities; prior to 1933 it was a major pest in many of them, but since then, for reasons not understood, it has virtually disappeared from many places where formerly it was abundant, and is of relatively little importance in the rest.

The citricola and soft (or: soft brown) scales are sometimes misidentified, and where there are few specimens this may be expected. (For discussion of soft scale see p. 724.) However, there are many important differences, not only in the scales themselves, but in the character of the infestations also. The soft scale is usually found on single twigs or on parts of the tree only, whereas the citricola scale occurs more or less generally over the entire tree or grove, especially when infestations are heavy. In general, the citricola scale is most commonly present in the lower part of the north side of the tree. Since there is normally but one generation of citricola scale a year, all the scales seen in any infestation will be of nearly the same size; whereas the soft scale has three or four generations a year, usually with some overlapping, and hence there may be different-sized scales on the same twig or leaf. There are also some differences in coloring. The citricola scale, when it approaches maturity, is gray; the soft scale is more of a brown color. The young of the citricola scale are very flat and much more transparent than the young of the soft scale. The citricola scale lays eggs; the soft scale gives birth to young. The citricola scale almost invariably matures on the twigs (fig. 235); many of the soft scale may mature on the leaves.

Injury caused by the citricola scale is referable to the extraction of juices from the plant and to the copious excretion of honeydew in which the sooty mold fungus grows. When infestations are severe, the tree is unable to bear its usual crop.

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[1] W. H. Ewart, unpublished data, 1948.

*Life history.*—This scale deposits eggs to the number of 1,000 to 1,500 over a period of thirty to sixty days. (For detailed discussion of this insect see Quayle, 1915.) Upon hatching, the young may remain beneath the parent scale for a few hours if the temperature is warm, or for a day or two if it is cooler. The young crawl about actively for about a day, after which they settle, for the most part, on the undersurface of the leaves. When infesta-

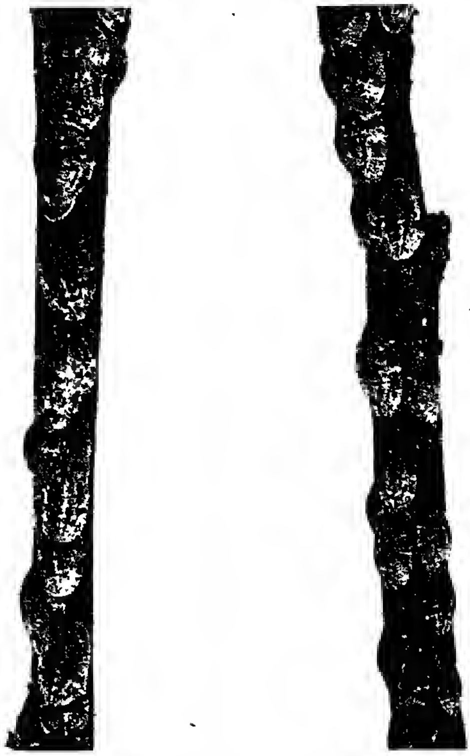

Fig. 235. Citricola scale, *Coccus pseudomagnoliarum* (Kuw.), on orange twigs. Mature females. (After Quayle, 1938*b*; courtesy Comstock Pub. Co.)

tions are severe, a great many also establish themselves on the upper side, and on the more tender twigs. The first molt occurs approximately one month after settling, and the second or last molt about one month after the first molt. The discarded skins may be detected as cornucopia-like objects, not unlike a bit of thread or lint, which often remain attached to the posterior end of the scale.

The eggs are deposited by this scale mostly in May or June; however, some are deposited in the latter part of April, and others in July and August. From the time of hatching until the following spring (about March) the scales are mostly on the leaves and tender twigs. During this time they have

grown very slowly, but after they migrate to the twigs, in early spring, they grow rapidly and are mature by the latter part of April.

Normally, there is but one generation a year. In the San Joaquin Valley in 1946 (Woglum, 1946*d*), and 1947, however, a partial second generation developed.

*Control.*—Formerly, fumigation was generally relied upon for control of the citricola scale, but about fifteen years ago the insect developed so high a degree of tolerance to fumigation that the method is no longer applicable over most of the infested area in southern California (Quayle, 1938*a*). In central California, where this insect is at present an important pest, fumigation is a satisfactory method of control in all localities except near Ivanhoe, Tulare County. Here, in an area approximately three to five miles square, the scale is strikingly resistant to HCN fumigation. The period during which effective control by fumigation can be obtained is relatively short even in the localities where the resistant race is not known to occur; it extends from about July 15 to September 15, and work done after the latter date may not be successful. In Tulare County, fumigation is the most effective combined control of the citricola and yellow scales.

Oil sprays are generally used for control of citricola scale. For control of this insect alone, light-medium oil used at 1⅔ per cent emulsion or 1½ per cent emulsive is satisfactory. However, when oil is employed for the combined control of citricola scale and yellow scale, it is necessary to use medium oil at 2 per cent emulsion or 1⅔ per cent emulsive.

Sulfur dusts and lime sulfur–wettable sulfur sprays were in general use for many years for the combined control of citricola scale and citrus thrips, and they are used now to a limited degree. Various formulations of DDT also show promise for this purpose. (See section on combined treatment for citrus thrips and citricola scale, p. 692.)

DDT applied as thorough coverage spray in late winter has been highly effective in control of citricola scale. The treatment should be completed by March 15, however, for best results. On the basis of results obtained in the 1946 and 1947 experiments, the following formulas are the most satisfactory:

A. 1½ pounds of 50 per cent DDT wettable powder
1½ gallons kerosene
100 gallons of water
or
B. 1½ gallons of proprietary preparation of kerosene containing 4 per cent DDT in solution

The DDT wettable powder used in formula "A" should be soaked in the kerosene for at least 20 minutes before addition to the water in the spray tank. The mineral-element-deficiency materials zinc and manganese can be added to the spray mixture of either of the foregoing formulas without seriously affecting the action of the DDT. Soda ash should be used instead of hydrated lime, however, as a neutralizing agent for the zinc and manganese materials, if such an agent is needed.

DDT has also given excellent control of citricola scale when applied as thorough coverage spray during the period from August 15 to November 1. The suggested formula is: 1 pound of 50 per cent DDT wettable powder and 1 gallon of kerosene per 100 gallons of water.

DDT cannot be generally recommended for control of citricola scale until more information is available concerning the effect of this material on the vedalia–cottony cushion scale complex. (For details see Ewart and DeBach, 1947, 1948.)

Parathion, in initial experiments in 1947, showed promise for control of the citricola scale, and studies with this material are continuing (Ewart and DeBach, 1948).

### Soft (Soft Brown) Scale, *Coccus hesperidum* Linn.

The soft scale has for many years been known by the common name of "soft brown scale," but the former common name has now been officially approved (Muesebeck, 1946). This insect is generally distributed throughout the world on a wide variety of plants and occurs commonly on citrus. However, only in South Africa is it considered a major pest of citrus (Matthew, in a personal interview).

The soft scale often appears in a heavy infestation on a part of one or a few trees in an orchard. In California the extensiveness of the infestation is usually related to the abundance of the Argentine ant. Where the Argentine ant population is kept down, the soft scale infestation is usually of short duration, owing usually to the attacks of parasites on the scales. When the ants are running over the scales, the work of the parasites is interfered with. Injury is done by the insects' feeding and by the sooty mold fungus that grows in the honeydew which they excrete. The scale attacks the twigs, smaller branches, and leaves. (For comparison with citricola scale, with reference to life history and habits, see p. 722.)

*Control.*—Control in South Africa and Australia is accomplished by fumigation or oil spraying. In California it is rarely necessary to use direct control measures. Instead, the Argentine ant is controlled by poisoned bait (see formula on p. 768), and soon thereafter the parasites usually reduce the population of the soft scale to an insignificant level.

### Delta Scale, *Lecanium deltae* Lizer

In Argentina, in recent years, the delta scale has become a pest of some importance. It also occurs in Brazil. Apparently, it attacks citrus only. The insects settle on the under side of the leaves, and, as a result of their feeding, depressions or "dents" develop and result in leaf deformities which constitute the main type of injury. The females deposit about 3,000 eggs each and there are two generations a year.

*Control.*—Because of the deformities in the leaves, it is difficult to cover the insects effectively with an insecticide. Spraying with 1½ per cent medium, emulsible, white oil while the scales are still transparent (young), or while the eggs are hatching, is the method favored in Argentina (Hayward, 1941).

### Green Coffee Scale, *Coccus viridis* (Green)

The green coffee scale, very damaging to coffee plants, is injurious to citrus in parts of tropical Asia (Clausen, 1933). It also attacks citrus in Florida, Colombia, and Brazil, but it is of minor importance in those regions. Oil spray is effectively used as a control in Florida (Fredrick, 1943).

### Orange Pulvinaria Scale, *Pulvinaria aurantii* Ckll.

The orange pulvinaria scale is a common and serious pest on citrus in Japan. It is also known from southern China. According to Clausen (1927), a very large quantity of honeydew is excreted when infestations are heavy, resulting in a dense mat of sooty mold fungus which not only interferes with proper functioning of the leaves but also prevents the proper and uniform ripening of the fruit.

*Control.*—Reasonably effective control is obtained through the use of kerosene emulsion (Clausen, 1927).

### Pulvinaria Scale, *Pulvinaria polygonata* Ckll.

This *Pulvinaria* species is evidently synonymous with *P. cellulosa* Green. According to Clausen (1933), it is one of the most important scale pests in the Malaysian region. It is of some importance also in Queensland, a region into which it was probably introduced and in which citrus is apparently its only host (Summerville, 1934). When infestations are heavy, honeydew is copiously excreted and the trees become black with the sooty mold fungus.

*Control.*—Resin soda fish oil mixture and petroleum oil spray are effectively used as controls in Queensland (Summerville, 1934).

### Red Wax Scale, *Ceroplastes rubens* Mask.

The red wax scale is the second most important citrus insect of Japan. It was first found at Nagasaki in 1887, and has since spread throughout the island of Kiushu and has been found at many separated places on Honshu. In tropical Asia, it is of no consequence as a pest on citrus (Clausen, 1927). In China and Australia it is important. In the latter country it is called the pink wax scale. The common name indicates the general color of the insect.

The females occur mainly on the young twigs and only occasionally on the fruit and foliage. There is one generation a year in Japan (Clausen, 1927), two generations in Queensland (Summerville, 1934). Injury is caused mainly by the sooty mold fungus which grows on the honeydew excreted by the scale.

In Australia, soap-soda spray, resin soda fish oil spray, or fumigation affords control if applied at the proper time.

### White Wax Scale, *Ceroplastes destructor* Newst.

The white wax scale, according to Gurney (correspondence), is the second most important citrus pest in Australia. For many years it was supposed that this injurious species was *Ceroplastes ceriferus* Anderson, but Zeck's investigations in New South Wales (1932) showed that all specimens from

*Citrus* were *C. destructor* and not *C. ceriferus*. The common name indicates the general color of the insect, especially the younger stages. The wax covering forms an irregular mass, the black or purplish brown body being only faintly visible. Injury is caused mainly by the sooty mold fungus that grows on the honeydew excreted by the insect.

In Australia, soap-soda spray, soda-oil spray, or resin-soda spray is used for control.

### FLORIDA WAX SCALE, *Ceroplastes floridensis* Comst.

The Florida wax scale is listed as among the important citrus insects of Egypt (Hall, 1924) and Palestine (Bodenheimer, 1930). It is also found occasionally on citrus in Florida, tropical Asia, and Japan. The insect itself is red, showing pink through the white wax covering. The wax is arranged as a large, rounded, central dome surrounded by six or eight smaller domes and separated from them by a depression. The young larvae are star-shaped. Injury is caused mainly by the sooty mold fungus that grows on the honeydew excreted by the insect.

Another species of wax scale, *Ceroplastes sinensis* Del. Guer., is of some importance in Spain and Italy (Freeborn, 1931).

*Control.*—Apparently, no treatment is made specifically for control of these wax scales. However, fumigation and oil-spray treatments for other scale insects reduce the population of the wax scales.

### COTTONY CUSHION SCALE, *Icerya purchasi* Mask.

The cottony cushion scale, a native of Australia, is found on citrus in almost all citrus-producing areas. It was introduced into California in 1868 and in the early 1880's was established as a serious pest in the citrus orchards of southern California. (For full discussion of this insect see Quayle, 1938*b*, and Essig, 1931.) In 1893 it was established in Florida, and in 1904 it was present in Japan.

More extensive commerce and increasingly rapid means of transportation account for the fact that many insects have greatly extended their range in recent years. Introductions usually follow, too, the main commercial routes, with the result that insects become established in new places in a seemingly roundabout way. Thus, the cottony cushion scale had existed for centuries in Australia, and citrus and other hosts had been growing in Japan long before they were growing in California, yet this insect went from Australia to Japan by way of America.

The severity and conspicuousness of infestations of the cottony cushion scale caused much concern to the citrus growers of California. Federal and state agencies, as well as private individuals, engaged in efforts to check this serious pest, and there resulted some of the most important developments in insect control, among which were cyanide fumigation in the field, the biological method of controlling insects, and quarantine. (For details of fumigation see pp. 771 ff., below; of biological control, pp. 602 ff., above; and of quarantine, chap. xv, pp. 813 ff., below.)

Neither fumigation nor spraying was successful in checking the spread of this insect, and it remained for the Australian ladybird beetle, or vedalia, *Rodolia cardinalis* (Muls.), introduced in 1888, to bring the scale under control. Since then, it has been only a minor pest of citrus in California. In fact, it cannot be considered as more than a potential pest except where this biological balance is upset.

*Injury.*—The insects suck the plant sap and excrete copious amounts of honeydew. which accumulate in large masses. The honeydew differs in appearance from that excreted by other common "unarmored" scale insects on citrus in somewhat resembling agglomerates of sugar crystals. Apparently,

Fig. 236. Cottony cushion scale, *Icerya purchasi* Mask., adults. Note white, fluted egg sacs. Tiny dark objects on egg sacs are newly hatched larvae or crawlers. (After Quayle, 1932.)

the chief injury to the plant is the direct effect of the insect's feeding. since the twigs and branches that are heavily infested are quickly killed. The entire tree may be killed. Young trees may be killed within a few months after the infestation becomes heavy.

*Life history.*—The conspicuous part of this scale insect is the large, white, fluted cottony mass which is secreted by the adult female and in which the 500 to 800 eggs are deposited (fig. 236). The younger stages have a slight secretion of yellow wax, and this, which also attaches to the cast skins from molting, will be seen in an infestation of this insect, particularly on the leaves where the young are often found.

The adult females occur mostly on the trunk, branches, and twigs. The young are usually most abundant along the midrib on the under side of the leaves.

*Control.*—No control is now practiced for this insect on citrus trees in California (nor, apparently, elsewhere), once the vedalia is introduced and becomes established. Experience indicates that the cottony cushion scale is very difficult to control with currently available insecticides. However, preliminary studies with the recently developed new insecticide, parathion, applied as sprays and dusts have shown promising results. (Ewart and DeBach, 1948.)

## MEALYBUGS

Mealybugs constitute a group represented by a limited number of species, several of which are among the more important pests of citrus trees. In fact there is but one species, *Pseudococcus citri* (Risso), the citrus mealybug (sometimes known as the common mealybug), that occurs as a pest of citrus over a very wide range. This species is perhaps of greatest importance in Spain, Italy, Algiers, Palestine, Egypt, South Africa, California, and Florida.

Five species of mealybugs are found on citrus trees in California, and some or all of them, with the possible exception of the Baker mealybug, may be found on citrus elsewhere. These species are: the citrus mealybug, *Pseudococcus citri* (Risso); the citrophilus mealybug, *P. gahani* Green; the Baker mealybug, *P. maritimus* (Ehrh.); the long-tailed mealybug, *P. adonidum* (Linn.), formerly considered *P. longispinus* (Targ.); and the Japanese mealybug, P. *krauhniae* (Kuw.) (Clausen, 1915; Smith and Armitage, 1931; and Quayle, 1938*b*). In Egypt the hibiscus mealybug, *Phenacoccus hirsutus* Green, is a serious pest of citrus (Freeborn, 1931). An additional species, the Mexican mealybug, *Phenacoccus gossypii* Towns. and Ckll., may be of concern to citrus growers in California because it is commonly present on a number of herbaceous perennials around the home. Thus far its occurrence on citrus has been occasional and perhaps accidental.

The chief difference in the external appearance of the different species of mealybugs is to be found in the waxy covering and the filaments of the same material around the margin of the bodies, particularly at the posterior end (fig. 237). The posterior filaments of the long-tailed mealybug are longer than the body, and slender; those of the Baker mealybug are slender, but much shorter than the body. In the citrus mealybug the filaments are short and thick, the posterior ones being slightly longer than the lateral ones. In the citrophilus mealybug there are usually two posterior filaments that are longer and stouter, tapering toward the tip. Also in this species the waxy covering is not uniform, but is broken by four small areas on each body segment which are sparsely covered, giving the appearane of four longitudinal lines. Also, the body fluid of this species is dark in color, whereas it is light-colored in the three species just described. The Japanese mealybug is similar to the citrus mealybug in its covering and filaments, but it is much larger when mature and its body fluid is dark-colored like that of citrophilus. The Mexican mealybug may be distinguished from the other species by its covering of coarse, granular wax, central longitudinal ridge, grayish body color, and elongated, compact egg sac.

Formerly, the citrus mealybug was the only one of importance as a citrus pest in California, seriously damaging in limited coastal localities particularly. It has not, however, been generally injurious in the past fifteen years, probably because of the activity of beneficial insects that have been introduced or propagated to combat this and other species. In 1913 the citrophilus mealybug, a new species, was found at Upland, the original infesta-

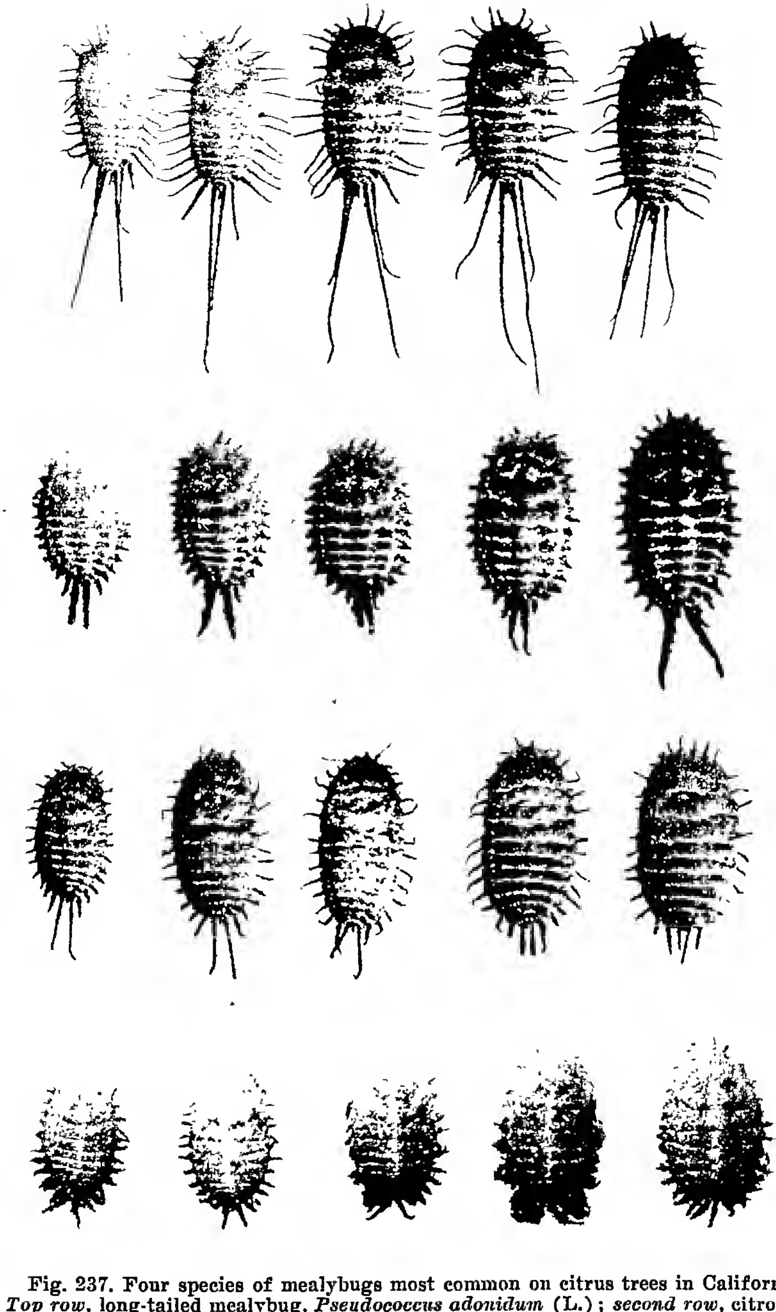

Fig. 237. Four species of mealybugs most common on citrus trees in California. *Top row*, long-tailed mealybug, *Pseudococcus adonidum* (L.); *second row*, citrophilus mealybug, *Pseudococcus gahani* Green; *third row*, Baker mealybug, *Pseudococcus maritimus* (Ehrh.); *bottom row*, citrus mealybug, *Pseudococcus citri* (Risso). (After Clausen, 1915.)

tion covering about 20 aeres. Subsequently this species spread rapidly over the citrus area of southern California until it had covered more than 100,000 acres. It became a mueh more serious pest than the citrus mealybug bceause of its more general distribution and more injurious effeet on the trees. The striking effeetiveness in biologieal eontrol of the citrophilus mealybug by the Australian parasites that were introdueed in 1928 was phenomenal (Smith and Compere, 1928; Compere and Smith, 1932). (For details see chap. xii, p. 610.) The Baker mealybug and the long-tailed mealybug are sporadic in oecurrence as pests of eitrus. The long-tailed species appears to be the more injurious of the two. In eommon with the preeeding two speeics, they thrive best under coastal eonditions. The Japanese mealybug oeeurs in but a small area in the Ojai Valley in Ventura County, where summer eonditions are warmer and drier than those of typieal coastal loealities. It is of interest to note that the Japanese mealybug is not known to oceur in Japan, although it has been observed in southern China by Clausen (1927).

Mealybugs injure the trees in much the same way as the unarmored scales, sueh as the blaek seale. They extraet the juiees from the plant and also exerete large quantities of honeydew in which grows the sooty mold fungus. This fungus makes a black eovering on the foliage and fruit, which interferes with the normal functions of the plant. Furthermore, mealybugs may eluster around the pedicel of the fruit and eause young oranges or lemons to drop in the early spring, and mature Valencias later in the season. When abundant, the masses of white, cottony secretion enveloping the eggs and oecurring over the tree and fruit also add to the detrimental effect of mealybugs.

*Life history.*—The life histories of the different speeies of mealybugs are somewhat similar and may be grouped together for this diseussion. (For details see Clausen, 1915.)

As many as 800 eggs are deposited in eottony fibers secreted for the purpose, over a period of 10 to 20 days. However, the long-tailed mealybug does not deposit eggs, but gives birth to young mealybugs. The young hatehing from the eggs erawl about and, unlike scale inseets, maintain their power of locomotion throughout their existenee, except that the females are usually stationary after egg laying begins, and the males are fixed during the pupal period. The young, in general appearanee, are like the adults exeept that they are smaller. The female undergoes three molts. The male, like the male of seale inseets, passes through a total of four molts and finally emerges as a winged inseet.

There may be four generations in the eourse of a year.

*Control.*—Chemical eontrol measures have not been satisfactory against mealybugs in California, with the possible exeeption of fumigation for control of the long-tailed species. Meehanieal eontrol measures, that is, washing the mealybugs off the trees with a large volume of water (1,000 gallons per tree) under low pressure (50 pounds), were in use against the eitrophilus mealybug (Boyee, 1929) prior to control of this speeies with parasites. Now, the biologieal method of eontrol is usually employed sueeessfully against all speeies. (For details see chap. xii.)

## WHITE FLIES

The general term "white flies" refers to a large group of tiny insects, of which the winged adults of many species are white; others vary from whitish to blackish. Only a few species of white flies are important pests of citrus, though relatively many species may occur on citrus plants.

White flies are related to scale insects and these two groups have certain characteristics in common. The larvae of many white flies resemble in general appearance the larvae of unarmored scale insects, and both are fixed to the host plant. Both groups of larvae excrete honeydew. Only the male of scale insects is winged; however, both sexes of the white fly are winged. The fact that the females are winged enables them to spread much more rapidly than scale insects. Thus they are hard to control because of the rapid infestation that is likely to occur from untreated citrus trees or other host plants.

Injury caused by white flies on citrus is twofold; sap is withdrawn from the tree, and the sooty mold fungus which grows in the honeydew excreted by the insect interferes with the normal functioning of the leaves. In Florida (Watson and Berger, 1937), furthermore, the presence of the sooty mold fungus favors increase of the purple scale.

### CITRUS WHITE FLY, *Dialeurodes citri* (Ashm.)

The citrus white fly was formerly considered the most important citrus pest in Florida (Morrill and Back, 1911; Watson and Berger, 1937) and in some of the other Gulf states. Its native home is India, where it sporadically becomes important. Although it occurs also in China, Japan, Brazil, and Chile, it is not considered an important pest in those countries. It was found at Marysville and Oroville, California, in 1907, and was later found in several other places in the Sacramento Valley and at Sacramento itself, and in several localities of limited extent in southern California. Eradication was at once undertaken wherever an infestation was found (Mackie, 1931*a*; Essig, 1931). Through careful inspection, a certain amount of host destruction, oil spraying, and fumigation the long campaign of attrition finally succeeded in 1942 (Armitage, 1944). However, in 1947 a light infestation of citrus white fly was again found in a very small area in Orange County and a program of eradication was begun immediately (Tubbs, 1947).

*Life history.*—There are four stages in the development of the white fly: egg, larva, pupa, and adult. The egg is oval, pale yellow, and 1/100 inch long. When numerous, the eggs give the leaves the appearance of being covered with pale yellow powder, since the individual eggs are scarcely visible to the unaided eye. They are deposited on the under side of the leaves and are fastened by a short stalk. The eggs, numbering about 100 per female, are laid in 8 or 10 days and hatch in 10 to 12 days into yellow, flat crawlers that avoid the direct light and settle after a few hours on the undersurface of the leaves.

In the course of the first molt the legs and antennae are lost. The larva is flat, transparent, and scalelike, and has transverse lines. After two other

molts the fourth-stage larva, which is commonly referred to as the pupa, appears. This stage is different from the others: much less food is taken than in the earlier stages, the insect is thicker, and the outline of the adult takes form. Finally, the pupal case splits crosswise on the back and the mealy-winged white fly (1/15 inch long) emerges (fig. 238).

In Florida there are three main generations in a year. The spring brood of adults is at its maximum in March, the summer brood in June, and the fall brood in the latter part of August and the first part of September.

*Control.*—Oil sprays are used for the control of this insect in Florida. (See Florida spray-and-dust schedule, p. 799. For discussion of entomogenous fungi attacking the citrus white fly in Florida see chap. xiii; and Watson and Berger, 1937.)

### Cloudy-winged White Fly, *Dialeurodes citrifolii* (Morg.)

The cloudy-winged white fly is another of the important white flies on citrus in Florida. It differs from the preceding species in that the egg is black instead of pale yellow and in the middle of each wing there is a darkened area which accounts for the common name of this species (Watson and Berger, 1937). Also, the period of development is about two weeks longer in summer than that of the citrus white fly. Both species are commonly associated in the orchards.

*Control.*—See paragraph on control of citrus white fly, just above.

### Citrus Black Fly, *Aleurocanthus woglumi* Ashby

The citrus black fly, one of the most destructive species of this group of insects attacking citrus, was first known in the Western Hemisphere in 1913, when it was found in Jamaica. Apparently it had been introduced from India. It became a major pest of citrus in Cuba and other islands of the West Indies, and in the Bahamas, Costa Rica, and Panama. (For full discussion of this insect see Dietz and Zetek, 1920.)

In 1935, this insect was found in Mexico at El Dorado, Sinaloa, where its rapid northward spread and its destructiveness to citrus are viewed with grave concern by the citrus industries of Texas, Arizona, and California. (For discussion of this insect in Mexico see Woglum and Smith, 1947.) In view of the fact that by May, 1947, the citrus black fly had spread northward in Mexico to Empalme, which is only approximately 270 miles south of the Arizona border, the citrus industry of California took immediate action to prevent or at least delay its spread into these two states. The industry made an appropriation of $25,000 for eradication of this insect from the area north of the Yaqui River and ultimately from the entire State of Sonora. Subsequently (early in 1948), funds became available to the U. S. Bureau of Entomology and Plant Quarantine, which permits that agency to assume responsibility for this important work in Mexico.

The campaign for eradication of the citrus black fly in northeastern Mexico was begun in November, 1947, under the direction of R. S. Woglum, as a coöperative project of the citrus growers of California and Arizona, the

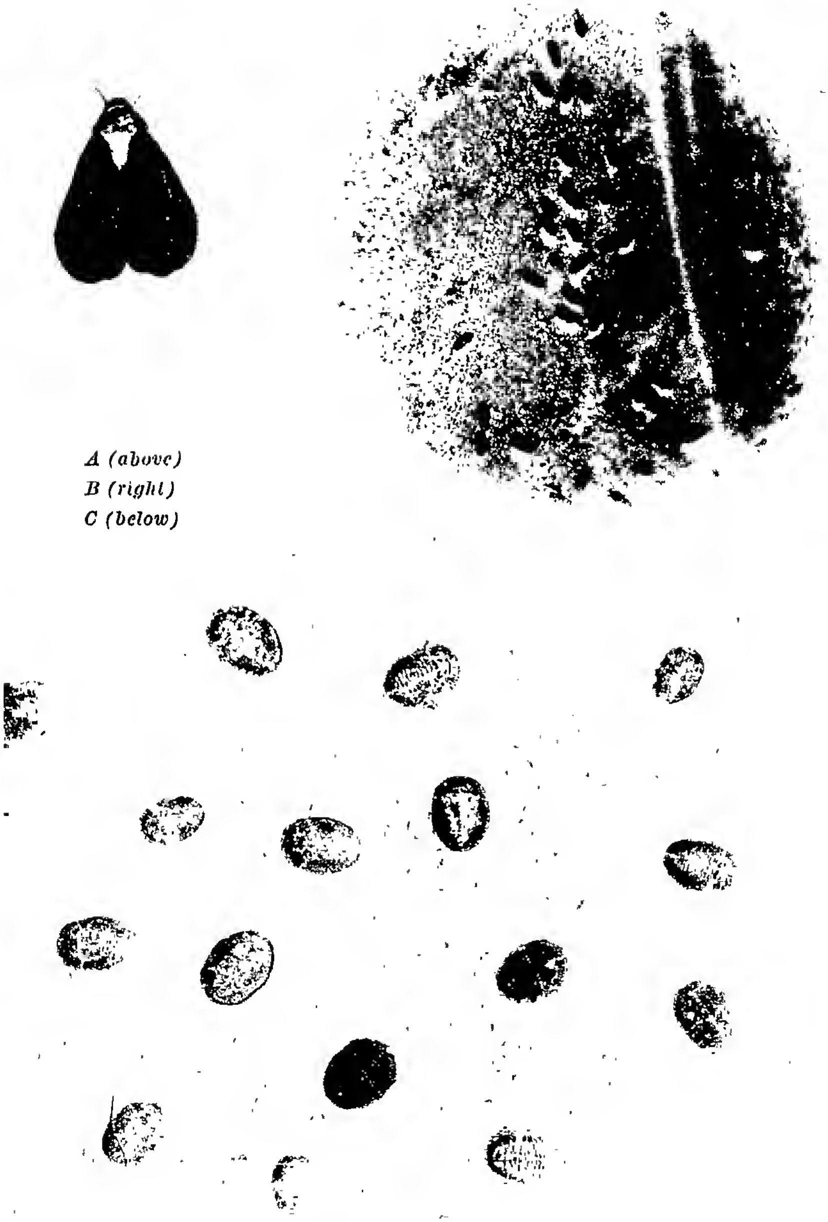


Fig. 238. Citrus white fly, *Dialeurodes citri* (Ashm.). *A*, adult; *B*, eggs; and *C*, larvae. (After Mackie; courtesy Calif. Dept. Agric.)

Mexican Department of Agriculture, the government and the citrus growers of the State of Sonora, Mexico, and the U. S. Bureau of Entomology and Plant Quarantine Laboratory in Mexico City. This entire project is being conducted under the general direction of Ingeniero Salvador Sánchez Colín, Director General of Agriculture of Mexico. Citrus and other host plants in the infested localities within the area north of the Yaqui River are being sprayed thoroughly with petroleum oil of light-medium grade in which powdered cubé root is incorporated. Excellent progress is being made in this campaign. (For details of the citrus black fly campaign in Mexico see Anon., 1947*a*; also Woglum, 1948*a*, 1948*b*.)

Following Clausen's introduction into Cuba from Malaya, in 1930, of the parasite *Eretmocerus serius* Silv., commercial control of the citrus black fly was obtained within eight to twelve months (Clausen, 1932). With the exception of parts of Mexico, the citrus black fly is now effectively controlled by this parasite in other areas on this continent.

ORANGE SPINY WHITE FLY, *Aleurocanthus spiniferus* (Quaint.)

The orange spiny white fly is an important pest of citrus in Japan and is the most injurious of the several species that infest citrus there (Clausen, 1927; Kuwana, 1928). It is also injurious to citrus in China and tropical Asia.

MARLATT WHITE FLY, *Aleurolobus marlatti* (Quaint.)

Marlatt white fly is considered the second most important species of white fly attacking citrus in Japan (Clausen, 1927). This species also occurs on citrus in India.

## PSYLLIDS

There are several species of psyllids, or jumping plant lice, that occur on citrus, and at least two of them are important. Both species are known by the common name, citrus psylla.

*Diaphorina (Euphalerus) citri* Kuway occurs on citrus in tropical and subtropical Asia (Clausen, 1933) and is considered of great importance as a pest in India (Husain and Nath, 1927). Not only is damage done by the sooty-mold fungus that develops on the copious quantities of honeydew excreted by the insects, but it also appears that the insect, in its feeding activity, injects some toxic material into the tree. In the Punjab, the damage has been complete loss of crop for several seasons, and afterward the death of most branches and sometimes the death of the trees in entire orchards.

*Control.*—Nicotine sprays are effective against the nymphs in the spring, and resin-soda sprays are effective against the adults in winter. The studies of Rahman (1941) show promising results from the use of dusts containing nicotine sulfate and sulfur.

*Trioza merwei* Pettey occurs on citrus as a minor pest in South Africa. Rhodesia, and Uganda (Van der Merwe, 1923). Nursery trees and young orchard trees are more seriously affected than older trees. The insects attack only the new growth, and where a nymph settles on the under side of the leaf a pit or open gall is formed. When these galls are numerous, the leaf is

curled and otherwise greatly deformed. Immature forms and adults void excrement profusely, and the soil beneath a heavily infested tree may have the appearance of having been dusted with a white powder.

*Control.*—Since this insect commonly attacks certain native Rutaceae, the removal of these wild hosts from the vicinity of the citrus planting is important in control. Pinching off infested shoots by hand at the early stage of the infestation may be practiced on small trees. Oil spray may be used for the young nymphs before the leaves become curled.

## APHIDS

At least five species of aphids or plant lice are important pests of citrus in various parts of the world. Four of them occur on citrus in California and Florida: the green citrus aphid, *Aphis spiraecola* Patch; the melon or cotton aphid, *Aphis gossypii* Glover; the green peach aphid, *Myzus persicae* (Sulz.); and the black citrus aphid, *Toxoptera aurantii* (Fonsc.). The green peach aphid and the melon or cotton aphid attack a wide varicty of hosts throughout the world. *Toxoptera aurantii* occurs wherever citrus is grown, and it is practically restricted to citrus as a host.

The fifth species is also known as the black citrus aphid, *Aphis citricidus* (Kirk.), and occurs in almost all citrus-growing areas except those in the United States; it is also commonly referred to in the literature as *Aphis citricola* van der Goot, or *Aphis tavaresi* Del G. It is mahogany brown in color, and has pale, slender antennae.

For field use, a general description of the four species of aphids that occur on citrus in the United States has been prepared by R. C. Dickson:

*Green citrus aphid.*—Wingless forms are relatively broad and almost square in general shape, and are deep, opaque, apple green in color. Winged forms have dark head and thorax and pale yellow-green abdomen.

*Melon or cotton aphid.*—Wingless forms are dark dull gray in color, although very young specimens are sometimes yellowish. Winged forms are entirely dark in color.

*Green peach aphid.*—Wingless forms are pale translucent yellow-green in color and appear somewhat diamond-shaped since the cornicles are held in a convergent position, making the posterior end appear narrow. Prealate nymphs are often pink in color. Winged forms have a conspicuous black patch on the upper surface of the abdomen.

*Black citrus aphid.*—Wingless forms: only mature females are black in color, and they are a very shiny black; immature wingless forms are mahogany brown. Winged forms are readily recognized by the black stigma, that is, a conspicuous spot on each wing.

The main injuries caused by aphids on citrus are two: (1) severe curling and deformation of young leaves and stunted growth of leaves and twigs (fig. 239); and (2) impairment of leaf functioning from the presence of sooty mold fungus, which grows in the copious quantities of honeydew execreted by the aphids. In California, when climatic and other conditions in spring favor prolonged activity of aphids and after the flush of growth is no longer suitable for them to feed upon, they attack the blossoms and newly set fruits.

Fig. 239. Injury caused by aphids, *Aphis spiraecola* Patch. and *A. gossypii* Glov., on orange leaves.

This may result in bumps on the fruit and crooked and otherwise impaired fruit stems which are readily broken off when the trees are sprayed for scale-insect control the following summer. Young trees are more severely injured by aphids than older trees.

In California, aphids are injurious chiefly during spring and early summer, and principally in the coastal and intermediate localities. Occasionally they may be damaging in such interior localities as Riverside and Redlands.

Lemons are usually not seriously affected. The green citrus aphid and the melon or cotton aphid are the two most important species, the former generally much more important than the latter. Like conditions obtain in Florida.

### Green Citrus Aphid, *Aphis spiraecola* Patch

The place of origin of this aphid is unknown. It first attracted attention in Florida in 1923, but was not distinguished from the melon or cotton aphid until 1924. Severe outbreaks of this aphid occurred there in 1924, 1925, and 1932 (Watson and Berger, 1937). The species was first recognized in California in 1925, and had probably been present in association with the melon or cotton aphid for several years at least (Quayle, 1938*b*). The green citrus aphid is so closely related to the green apple aphid, *Aphis pomi* De G., that it is possible to distinguish between the two only in the sexual forms, which have never been found on citrus but have been found sparingly on *Spiraea* in Florida and California.

*Life history.*—The biology of this aphid has been extensively studied in Florida by Miller (1929) and others. Reproduction occurs asexually throughout the year, the young being born alive. The length of the nymphal period, that is, the period between birth and reproductive maturity, ranges from 4 to 16 days, depending upon temperature and food conditions. The daily rate of reproduction varies from 1 to 16 young aphids per female. The total number of young produced by a single female may exceed 100. The length of life ranges from 12 to 33 days. Winged forms commonly develop when the aphid colony becomes crowded or when the foliage begins to harden, whereas practically no winged forms are present when the aphids feed on very tender growth and are not too crowded. In California, many aphids pass the winter in constantly reproducing colonies on citrus. It is probable that these colonies are the principal source of the spring population.

### Melon or Cotton Aphid, *Aphis gossypii* Glover

This species infests citrus trees with the beginning of the spring flush of growth, coming from some of its many host plants that may be growing as cover crops in the orchard or near by. Reproduction without fertilization is continuous throughout the year in Florida (Goff and Tissot, 1932), and apparently in California also. Other general features of the biology of this aphid are essentially similar to those mentioned for the green citrus aphid.

## CONTROL OF APHIDS

In certain seasons and in certain localities in California, particularly in those localities which lie between the coast and the interior, it is difficult to determine whether treatment for control of aphids on larger trees is justified; the incidence and effectiveness of predators and parasites of aphids—and sometimes entomogenous fungi—which may render treatment unnecessary are unpredictable. However, there is no doubt about the advisability of aphid control on small trees. (For information regarding biological control of aphids see Watson and Berger, 1937, and Quayle, 1938*b*.)

Treatment for control of aphids on citrus should be made before the populations have built up to an appreciable degree, and hence before much curling of the leaves has occurred. Nicotine applied as dust or spray has been the standard material for control of aphids on citrus for many years. However, in recent years certain formulations of rotenone applied as spray have been effectively and widely used, and currently (1948) hexaethyl tetraphosphate (HETP) and tetraethyl pyrophosphate (TEP) are being used effectively in a limited way commercially. Prior to the development of boom sprayers (p. 791) and spray dusters (p. 794), it was generally considered most practical to dust for aphid control on large trees and spray small trees. The critical shortage of nicotine since 1943 and the lack of any other highly effective aphicide that could be used as a dust, together with the development of equipment for the rapid application of aphicide sprays, has made liquid application more practical than dusting in some localities at least. In some seasons and in certain areas it is necessary to apply two or three treatments in order to obtain satisfactory control.

In California, formulas commonly used for control of aphids on citrus are as follows:

Nicotine sulfate (40 per cent nicotine) .......... ¾ pint
Calcium caseinate .......... ½ pound
Water .......... 100 gallons

or

Proprietary derris or cubé extractives preparation containing 2.5 per cent rotenone 1 pint
Water .......... 100 gallons

or

Powdered cubé or derris root containing 4 to 5 per cent rotenone .......... ½ pound
Emulsive oil, light-medium grade .......... ½ gallon
Water .......... 100 gallons

or

Proprietary oil preparations containing 0.1 per cent rotenone .......... ½ gallon
Water .......... 100 gallons

or

Proprietary preparation of HETP or TEP containing 20 per cent TEP .......... 1 quart
Water .......... 100 gallons
Applied with spray duster at 100 gallons per acre

or

Dust mixture containing 4 per cent actual nicotine used at the rate of 50 pounds per acre

or

Proprietary dust mixture containing 0.5 per cent actual TEP used at the rate of 80 pounds per acre.

## LEAF HOPPERS

Although a number of species of leaf hoppers may be found on citrus trees, they are ordinarily not injurious. One species, however, the potato leaf hopper, is of importance in California.

### Potato Leaf Hopper, *Empoasca fabae* (Harr.)

The potato leaf hopper has been important as a pest on oranges in Tulare County, California, since about 1936 (Lewis, 1942). The leaf hoppers migrate into the citrus orchards in the fall and feed on the oranges as soon as the yellow color begins to appear in the peel. Navels are attacked first, usually in early October, and Valencias are attacked about one month later. The sign of injury is spotting, at the point where the leaf hopper has fed, which results from release of the oil naturally occurring in the peel. The amount of injury done varies considerably. In severe cases more than 50 per cent of the fruit may be rendered unmarketable. There has been no evidence that the leaf hoppers reproduce on citrus.

*Control.*—Satisfactory control is effected by repelling the leaf hoppers through the use of lime spray to which zinc sulfate is usually added for the zinc needs of the tree (Lewis, 1942). On Valencias the hydrated lime is used at the rate of 30 pounds per 100 gallons of water. On navels, which require protection for a shorter time than Valencias, the amount of lime is reduced to 20 pounds per 100 gallons of water. Coverage is necessary on the outside of the tree only.

## PLANT BUGS

There are a number of species of true plant bugs in the United States and elsewhere that attack citrus sporadically, and often the injury is minor, but there are two species in Australia, and at least one species in China, that are of more general importance. They are the bronze orange bug and the larger horned citrus bug in Australia, and the citrus stinkbug in China.

### Bronze Orange Bug, *Rhoecocoris sulciventris* Stahl.

This species effects important citrus losses in Australia. Both the nymphs and the adults feed on the tender growth and on the blossoms and young fruits. The affected twigs wilt and the flowers and young fruits that have been attacked fall off. When infestations are heavy, most of the young fruit will drop.

The fifth-stage nymphs and the adults of this insect aggressively discharge—to a distance of as much as two feet—a secretion of almost colorless volatile liquid that may cause temporary blindness if it comes in contact with a person's eyes, and severe burning if it lodges on a tender skin (Summerville, 1935*a*).

*Control.*—Jarring the trees to dislodge the nymphs, and destruction of them on the ground where they congregate at an appropriate barrier, has been effectively practiced. However, spraying with a mixture of resin, soda, and fish oil has been most satisfactory.

### Larger Horned Citrus Bug, *Biprorulus bibax* Bred.

This species has for many years been a pest of importance, particularly in Queensland. Its native host plants are the desert lime and the finger lime. The lemon is most severely attacked, and losses up to 90 per cent have occurred.

The bugs prefer feeding on fruits to feeding on foliage, and soon after they feed the fruits drop.

The adults as well as the larger nymphs eject an evil-smelling secretion which stains one's skin a bright yellow. It is irritating to tender skin; however, it is not so objectionable as the secretion ejected by the bronze orange bug (Summerville, 1931).

*Control.*—This bug is very difficult to control and the procedure is complicated. It involves crop removal at a certain season, hand picking, fumigation, and spraying with a mixture of resin, soda, and fish oil. (For details see Summerville, 1931.)

### CITRUS STINKBUG, *Rhynchocoris humeralis* Thunb.

This stinkbug occurs in China, Formosa, Burma, and India, where it attacks oranges principally. The nymphs and adults feed on fruits of all sizes; however, they show a preference for the larger, nearly ripe ones (Hoffman, 1928).

### PUMPKIN BUG OR SOUTHERN GREEN STINKBUG, *Nezara viridula* Linn.

In Florida this is the most important of several species of plant bugs, and it may cause serious losses. On young trees the succulent twigs are killed as a result of feeding by this bug. More important, however, is the loss of fruit resulting from the feeding of these bugs in the fall; according to Watson and Berger (1937), it may sometimes amount to half the crop. The bugs congregate on the fruits and suck out large quantities of juice.

*Control.*—Collection of the bugs by jarring them off the trees into nets while the temperature is below 70° F. is practiced. Certain cultural operations, such as proper selection and proper handling of the cover crop, are important preventive measures (Watson and Berger, 1937). Recently, benzene hexachloride has been used for control. (See Florida spray-and-dust schedule, p. 799.)

### LEAF-FOOTED PLANT BUGS, *Leptoglossus* Sp.

*Leptoglossus phyllopus* (Linn.) occurs on citrus in Arizona and the Gulf states. In Florida it is most important as a pest of mandarin and tangerine oranges, although it frequently attacks others (Watson and Berger, 1937). The bugs congregate in colonies on single fruits or trees. They extract large quantities of juice from the fruit and render it worthless.

*Control.*—Collection of the insects as practiced for the pumpkin bug has been employed for control, and benzene hexachloride is now used in combating it. (See Florida spray-and-dust schedule, p. 799.)

### WESTERN LEAF-FOOTED PLANT BUG, *Leptoglossus zonatus* (Dallas)

This species has occasionally caused considerable loss of citrus fruits in the Imperial Valley of California in restricted localities, usually in close proximity to pomegranates. It is primarily a pest of pomegranates, and it spreads the fungus *Nematospora coryli* which causes heart rot of that fruit.

This insect has not been associated with the spread of any disease of citrus. The bugs attack tangerine oranges as well as other oranges and grapefruit, usually congregating in large numbers on individual fruits, rendering them worthless (Quayle, 1929*a*).

*Control.*—Elimination of pomegranate trees in the vicinity of citrus orchards alleviates the problem so far as citrus is concerned. Maintenance of turkeys in the citrus orchard to eat the plant bugs that are jarred from the trees in the cooler early morning hours has been effectively used as a control measure.

### False Chinch Bug, *Nysius ericae* (Schil.)

The false chinch bug is occasionally very destructive in California, on small citrus trees particularly: in fact, it kills annually an undetermined number of small trees. The bugs are small and relatively inconspicuous, and erratic in their occurrence in destructive numbers. Their presence is usually associated with improper handling of the cover crop. The nymphs and adults congregate in great numbers on the younger wood, which usually is quickly killed.

*Control.*—DDT affords most effective results in control. A 5 per cent DDT dust, or a spray containing 1 pound of actual DDT in 100 gallons of water, may be used. The trees and the ground beneath the trees should be treated.

## FRUIT-PIERCING MOTHS

In South Africa, Australia, many sections of Asia from Japan to the Dutch East Indies, and India, a number of moths called fruit-piercing moths are important as citrus pests. Among the important species listed are: South Africa, *Ophideres materna* Linn. and *Serrodes partita* Fabr.; Australia, *Orthresis fullonica* Linn., *Maenas salaminia* Fabr., and *Ophideres materna* Linn.; Japan, *Ophideres tyrannus* Green, *Calpe excavata* Butl., and *Calpe capucina* Esq.; India, *Othreis fullonica* Linn., *Ophideres materna* Linn.; and in China, the Philippines, Malaya, and the Dutch East Indies, *Othreis fullonica* Linn.

These are relatively large moths which, at night, insert a long, slender proboscis into the fruit for the purpose of feeding. The punctures made by the mouthparts are distinct holes, and decay organisms soon enter the affected fruits, which usually drop within a few days. According to Clausen (1927), the navel orange cannot be extensively grown in parts of Japan because of the abundance and severity of attack by *Ophideres tyrannus* Green. The larvae of these moths do not feed on citrus but instead develop on other vegetation, usually weeds.

*Control*—Control of these moths is difficult, and no entirely satisfactory method has yet been developed for all species. Susainathan (1924) obtained successful control in an area of Madras (India) through elimination of the host plants on which the larvae develop. The use of poison baits and light traps for the moths has been widely tested, but without satisfactory results. In some places the fruits are actually enclosed in baskets or muslin bags to prevent attack by the moths.

## Group II

Grasshoppers (below); katydids, p. 743; larvae of moths and butterflies, p. 743; beetles, p. 748; and snails (p. 751) which cause injury by chewing and consuming foliage and fruit or chewing into the fruit superficially.

### GRASSHOPPERS

Grasshoppers are general feeders and ordinarily are not singled out as citrus pests; nevertheless, like any other plant that may be in the path of an invasion, citrus trees do not escape damage. These insects feed voraciously on the foliage, fruit, and green bark of the twigs, and in parts of South Africa and the eastern Mediterranean basin the trees in large areas may be completely defoliated when attacked by large swarms of locusts.[1] A number of species have been recored as damaging to citrus in various parts of the world. Among the more common species that damage citrus are: the desert locust, *Schistocerca gregaria* Farsk., in the Mediterranean region; the brown locust, *Locustana pardalina* Wlk., and the red locust, *Nomadacris septemfasciata* Sert., in South Africa; *Schistocerca paranensis* Burn., in Central and South America; *Melanoplus mexicanus* (Scud.), *M. devastator* (Scud.), *Oedoleonatus enigma* (Scud.), and *Camnula pellucide* Scud., in California; *M. mexicanus* (Scud.) and *M. differentialis* (Thomas), in Arizona; and *Schistocerca americana* (Drury), in Florida. Although a few grasshoppers may be generally present in citrus groves, the injury done is usually of little consequence; it is mainly the migratory swarms that need to be guarded against, and community rather than individual action is then important. Where an invasion of grasshoppers threatens an individual planting or a few contiguous plantings, as commonly occurs in California and Arizona, serious injury may be limited to a few outside rows of trees if the following methods are used.

1) Distribute poisoned bait on the ground in a wide strip adjacent to the planting and between each two rows of the first three or four rows of trees.

FORMULAS FOR BAIT*

| | |
|---|---|
| Coarse wheat bran | 100 pounds |
| Sodium arsenite (32 per cent arsenious oxide) | 1 quart |
| Water | 10 to 14 gallons |

or

| | |
|---|---|
| Coarse wheat bran | 50 pounds |
| Sawdust | 50 pounds |
| Sodium arsenite (32 per cent arsenious oxide) | 1 quart |
| Water | 15 gallons |

Note: 5 pounds of sodium fluosilicate may be substituted for the sodium arsenite in either of the formulas given above.

[1] The migratory grasshoppers, or the phase of a species of grasshopper that becomes migratory, are referred to as locusts.

* Supplied by W. H. Wright, Agricultural Commissioner, Riverside County, California, who reports effective results from the use of any of the indicated formulas.

The poison and the water are well mixed together and this mixture is then added gradually to the bran. Thorough and proper mixing is essential. The bait is distributed in the morning or evening, since grasshoppers feed mostly between temperatures of 55° and 80° F. and ascend vegetation when the soil is hot in the middle of the day. (For general discussion of grasshoppers and their control see Parker, 1939.)

2) The first three or four outside rows of trees toward the insect invasion may also be sprayed or dusted with chlordan preparations, the amount for an application being 1 pound of the toxicant per acre. In Arizona, according to Roney (correspondence), the regular sodium fluosilicate bran sawdust bait will give good results in control if the grasshopper populations are not too high. But if the citrus orchard adjoins an alfalfa field, baits are of little value, and resort to direct treatment of the trees with chlordan is desirable. In Florida, benzene hexachloride, chlordan, or chlorinated camphene ("Toxaphene") may be used successfully on citrus trees when immediate control is necessary. However, judicious cultivation practices in groves where grasshoppers are expected to be a problem will alleviate the damage (see Florida spray-and-dust schedule, p. 799).

## KATYDIDS

Injury to citrus by katydids occurs occasionally in many places where citrus is grown. In Australia, the citrus green tree hopper, *Caedicia strenua* Wlk., and the inland green tree hopper, *Caedicia simplex* Wlk., have become more or less permanent pests on citrus in New South Wales (Hely, 1945). In California, the fork-tailed katydid, *Scudderia furcata Bru.*, and the angular-winged katydid, *Microcentrum rhombifolium* Sauss, are the common species on citrus (Horton and Pemberton, 1915). In Florida, the common species on citrus are *Crytophyllus concavus* Bru. and *Microcentrum retinerve* Burm. (Watson and Berger, 1937).

Katydids do not migrate, as many species of grasshoppers do, and most of the species that attack citrus pass their entire life cycle on the citrus trees. Both young and adult katydids feed on the foliage and the young fruits particularly. Small areas on the surface of the young fruits are gouged out, which may result either in early dropping, or bad scarring or other deformation when they are mature.

*Control.*—Cryolite used at a concentration of 50 per cent in a dust mixture or used as a spray at 4 pounds per 100 gallons of water affords effective control of katydids in California.

## THE SO-CALLED ORANGE WORMS

*Orange worms in California.*—Larvae of four species of small moths attack oranges in certain areas of southern California. The term "orange worms" is commonly used locally to refer to these insects. The species concerned are orange tortrix, *Argyrotaenia citrana* (Fern.); pyroderces, *Pyroderces rileyi* (Wals.); holcocera, *Holcocera iceryaella* Riley; and platynota, *Platynota stultana* (Wals.). Pyroderces has sometimes been referred

to as the "pink scavenger worm" because it is pinkish in color and has scavenger habits. The larvae of all four species may be found on the same tree. The most important ones at present, however, are the orange tortrix and the pyroderces. One other species, the navel orange worm, *Myelois venipars* Dyer, may be found in certain areas feeding inside of oranges in which some imperfection exists; but it does not attack sound fruits.

The principal injury caused by orange worms is essentially the same. from the fact that the larvae feed on, and partly in, the fruit. Fruits in a cluster are generally more subject to attack than single fruits, and the larvae commonly feed in the area where the fruits are in contact with one another. Many of the affected fruits drop; and those that do not drop are a packing-house problem since additional expense is entailed in sorting, in an attempt to prevent affected fruits from being packed, and furthermore, a small number of fruits with so-called "pinhole" injuries are likely to be packed inadvertently, with the result that decay may occur in transit.

*Orange tortrix.*—This is the most important species in California. It is recorded from Florida and Spain but is not considered important in either place.

Larvae of the orange tortrix feed more extensively on the peel and into the pulp of the orange than any of the other species (fig. 240); consequently, affected fruits drop relatively soon after attack, which is not so likely to occur when they are injured by any of the other three species. In spring particularly, the newly hatched larvae may roll and web together the newly developing leaves while feeding on them.

The principal damage from orange tortrix on navel oranges occurs mostly in late fall and winter. This was formerly observable of Valencias also, but in recent years the damage occurring in winter has generally been slight, except in a few scattered orchards, and the late spring and summer damage has been of greatest consequence. The orange tortrix occasionally attacks lemons. (For full treatment of the biology of orange tortrix see Basinger. 1938.)

*Pyroderces.*—Pyroderces, or the pink scavenger worm, has become generally abundant on oranges in Orange County, California, since 1939. Although it is predominantly a scavenging insect, definite evidence shows that it does feed on sound oranges still on the trees (Boyce, Korsmeier, and Dickson. 1944). There is a possibility, however, that its feeding on the fruits may be accidental. When infestations are heavy, the larvae are very numerous on the fruits; in fact, as many as twenty have been observed in one mass of debris webbed on a single orange. When they occur in such numbers, apparently only one or two of the larvae present may feed on the fruit. Laboratory studies have corroborated field evidence that pyroderces larvae may, at various times in their development, feed on the peel, and sometimes inward as far as the albedo, of ripe Valencia oranges.

Feeding by the pyroderces larva is fairly distinct from that of the orange tortrix; under field conditions, it generally makes one or more small shallow holes in the orange peel. The holes rarely extend into the albedo.

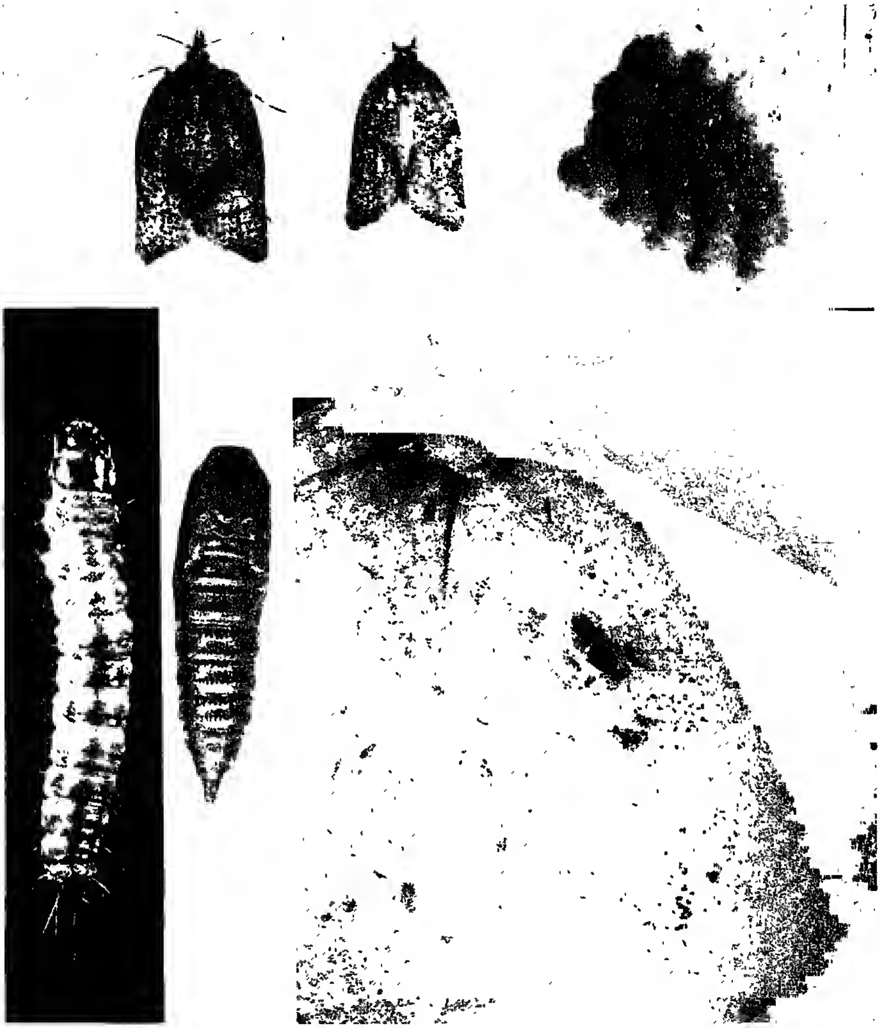

Fig. 240. Orange tortrix, *Argyrotaenia citrana* (Fern.). Adult female, male, eggs, larva, pupa, and typical injury by larva on orange fruit. (After Basinger.)

*Holcocera.*—Injury by holcocera larvae resembles that caused by pyroderces. Likewise, the holcocera larvae have scavenger tendencies, though less marked. Holcocera thrives best on "dirty" trees, such as result from heavy infestations of mealybugs. This species has not been of much importance in recent years except in an occasional Valencia grove.

*Platynota.*—Platynota is the least common of the four species of orange worms. It is doubtful that this insect causes important economic damage to citrus.

*Control.*—Cryolite is the most effective material for practical control of orange tortrix and holcocera. However, cryolite does not offer promise of effective control of pyroderces.

The control of orange tortrix on navels is much simpler than on Valencias. The cryolite treatment applied on navels in the period from May through August usually affords positive and highly satisfactory results. For maximum insurance against orange tortrix damage on Valencia oranges, it is necessary to apply a treatment in the fall to protect against drop during the winter season, and another treatment in May or June to protect against drop during the summer season. When treatment in the fall is necessary or desirable, either a spray incorporating the cryolite with the regular oil spray for scale insects should be applied, or a spray treatment of cryolite should be given after the oil spray has been applied. *Under no circumstances should cryolite be added to the regular oil spray treatment without approval of the manufacturer of the oil being used.*

In the spring treatment, applied in late May or early June, a dust mixture containing 50 per cent cryolite used at 1 pound per tree is most commonly employed; however, a spray application of cryolite, at 3 pounds per 100 gallons of water, is somewhat more effective.

Cryolite may be satisfactorily incorporated with DN-Dust as a dust treatment for the combined control of orange tortrix and citrus red mite (spider). The proprietary preparation DN-Dust D8 with cryolite has been generally used as a spring treatment for this purpose. When DN-111 is used in a spray treatment during the spring season for control of citrus red mite, cryolite may be added to the spray mixture, using a dosage of 3 pounds of cryolite per 100 gallons.

It is difficult to judge whether treatment for control of orange tortrix is justified at a time when maximum results would be obtained. In fact, no entirely satisfactory criterion is at present known. Therefore, except in those groves which have a history of annual losses from the activities of tortrix, or in which an infestation is heavy enough to require control measures, treatment must necessarily be viewed as an insurance problem. (For further information on control of orange worms see Boyce and Ortega, 1947.)

### Citrus Flower Moth, *Prays citri* Mil.

The citrus flower moth often injures the blossoms and young fruits of lemons, in Sicily particularly (Quayle, 1938*b*). It occurs throughout the Mediterranean region, and in Ceylon, India, the Philippines, and New South Wales. The blossoms of all citrus varieties are subject to attack. The larvae, tunneling in the flower, damage most of the floral parts directly, and they also web the parts together.

A related species in Malaya, *Prays endocarpa* Meyr., does not attack the blossoms, but feeds entirely upon the fruit. The newly hatched larvae bore into the fruit, and a gall-like swelling develops on it at the point of entry. When the larvae are numerous the infested fruit has a knotty appearance (Padgen, 1931; Clausen, 1933).

### FRUIT-TREE LEAF ROLLER, *Archips argyrospila* (Wlkr.)

The fruit-tree leaf roller is occasionally damaging to oranges in a limited locality in Tulare County, California (Woglum and Lewis, 1947*a*). The larvae, upon hatching in the spring, roll and web the newly developing leaves together and consume part or all of the leaf tissue. In severe infestations most of the flush of spring growth may be severely injured or destroyed.

*Control.*—A 2 per cent DDT plus 85 per cent sulfur dust, or a 5 per cent DDT-talc dust, were effectively used in control of this insect in 1947 (Woglum and Lewis, 1947*a*).

### BOLLWORM, *Heliothis armigera* (Hbn.)

The bollworm, also called the cotton bollworm, the corn earworm, and the tomato fruitworm, and often referred to in the literature as *Heliothis obsoleta* Fabr., is one of the important citrus pests in South Africa and Rhodesia, where apparently it had been present for some thirty years prior to its first attack on citrus, about 1925. It became destructive of citrus soon after the beginning of cotton growing in that part of the world (Jones, 1936). The eggs are deposited, in late August and September, on the blossom buds, blossoms, and leaves. Upon hatching, the young larvae feed on the unopened blossom buds, the open blossoms, the young fruit, and sometimes on the young foliage. A single larva wandering about may seriously injure or destroy many blossoms and young fruits. If injured young fruits do not drop, they may be so badly scarred that they are either reduced in grade or unfit for export. When infestations are abnormally severe the crop may be a total loss. In Valencia orange groves in which the mature crop of fruit has not been picked before the blooming period, and hence before the infestation of the bollworm, the mature fruit may be severely damaged. In fact, the large bollworm larvae may entirely consume a mature orange (Hamersma, 1943).

*Control.*—Cryolite and sodium fluosilicate afford satisfactory control (Roux, 1938).

## CUTWORMS

A number of species of cutworms are occasionally of localized importance on citrus. It is not uncommon for cutworms that are feeding on the cover crop in a citrus orchard to move to the trees when the cover crop is worked under. Sometimes there are migrations from adjoining areas into citrus orchards. An appreciable amount of damage is done to the fruit, especially on the lower branches of the trees.

*Xylomyges curialis* Grote and *Parastichtis purpurea* var. *crispa* were abundant on oranges in 1934 and 1935 in a limited locality in Tulare County, California. Cryolite dust afforded effective control.

## LEAF-EATING BUTTERFLY LARVAE

A large number of species of swallowtail butterfly larvae, commonly called "orange dogs," feed on the foliage of citrus throughout the world.

They are fairly large when mature, and many of them are colorful. When disturbed, the caterpiller ejects from the region behind its head a two-pronged hornlike process (osmeteria) from which is emitted a disagreeable odor. When the larvae are fairly abundant on the trees at fruit-picking time, the odor is very objectionable to the pickers. The larvae consume the foliage; in many citrus-growing areas of the world, trees, especially young ones, are at times defoliated. The lemon butterfly, *Papilio demoleus* Linn., is considered the most important leaf-feeding insect in India. When, in 1940 and 1941, serious outbreaks occurred in the Central Provinces, some orchards were completely defoliated (Hayes, 1945). Hand picking of the caterpillars and eggs of this species is practiced for control. This species is also of importance in China, Formosa, Malaya, and Burma. *Papilio polymnestor* Cram. and the citrus leaf caterpillar, *Polytes* Linn., are also important species in India and China particularly. *Papilio anactus* W. S. M. and *P. aegeus* Don. attack citrus in Australia; *P. machaon* Linn., in Palestine; *P. anchisiades* Esp., *P. crassus* Cram., and several others, in Central and South America; *P. cresphontes* Cramer, in Mexico and Florida; and *P. zelicaon* Lucas, in California (Quayle, 1938*b*).

## BEETLES THAT EAT THE FOLIAGE, FRUITS, AND ROOTS

A large number of beetles, principally weevils or snout beetles, attack citrus throughout the world. Generally, the adults feed on the citrus tree aboveground and the larvae develop on the roots. Since the adults of many of the species of weevils are incapable of flight, a barrier placed around the trunk of the tree to prevent the beetles from gaining access to it is often useful in control. Among the more common or important species are the following.

### FULLER'S ROSE BEETLE, *Pantomorus godmani* (Crotch)

Fuller's rose beetle is a grayish brown beetle, about one-third inch long, commonly observed on citrus foliage on the lower parts of mature trees or on all foliage of young trees. Characteristically, it eats away the edges of the leaves (fig. 241). The larva is a yellowish-white curved grub which feeds on the roots of citrus trees and other plants, eating away shallow surface channels, an injury which when general is important. The most serious injury is done to young trees, particularly their foligae. The beetle occurs on citrus in many countries.

*Life history.*—The eggs, in masses of from 10 to 60, are laid in crevices in the bark of citrus trees and under the calyx of the fruit. The larvae, upon hatching, go immediately to the ground, where they live until the following year (Quayle, 1938*b*). After pupation in the soil, the beetles emerge the following summer.

*Control.*—When injury to old trees requires treatment, the lower half of trees on which the beetles feed may be dusted with a 50 per cent cryolite dust or may be sprayed with cryolite, using 3 pounds to 100 gallons of water.

For small trees, such as interplants, cryolite dust or spray may be used,

or, since the beetles cannot fly, a barrier may be placed around the trunk, preventing them from ascending the tree. Those that may already be on the trees should first be shaken off. The barrier may consist of a sticky banding material, which should not be applied to the tree directly, but over a coating of such material as grafting wax, or over a paper band.

Fig. 241. Injury caused by Fuller rose beetle, *Pantomorus godmani* (Crotch); adults feeding on foliage. (After Quayle, 1938*b*; courtesy Comstock Pub. Co.)

DDT in both dust and spray formulations is highly effective for control of this beetle, but the general use of this material on citrus cannot yet be recommended.

CITRUS SNOUT BEETLE, *Sciobius granosus* Fahr.

The citrus snout beetle is apparently indigenous to Natal, South Africa, where it was first observed on citrus in the Muden Valley in 1931. It has since become an important citrus pest in parts of the Transvaal and Natal.

The adult is about one-half inch long, dull brown in color, and the wing covers are rugose. Adults are not able to fly. They feed mostly at night, preferring the foliage and young leaves. Larvae develop on the roots, essentially feeding on the soft bark of the root (Matthew and Roux, 1936).

*Control.*—The control program for this insect is somewhat complicated. Among the procedures followed are: clearing brush and undergrowth from riverbank areas adjoining orchards; maintaining a clean, cultivated barrier zone throughout the summer; placing special barrier collars and traps on the trunk of the tree; jarring the tree to displace beetles, and collecting them on canvas placed beneath the tree; and maintaining trap-crop "clumps" (2 feet square) midway of each four trees, poisoning the beetles in the "clumps" with cryolite or sodium fluosilicate, and treating the trees with cryolite or sodium fluosilicate. (For details of the control program see Matthew and Roux, 1936.)

### Citrus Root Weevil, *Pachnaeus litus* (Ger.)

The citrus root weevil occurs on citrus in Florida, but is considered of importance mainly on limes on the Florida Keys (Watson and Berger, 1937). The adults feed on the blossoms and leaves; the larvae, on the roots. According to Wolcott (1933), this species is the most common and injurious one of a number of related species attacking citrus in Cuba and Jamaica. There, it also attacks the young fruits, and the feeding scars become more pronounced as the fruit matures.

*Control.*—Hand picking is practiced for control in the West Indies.

### Dicky Rice Weevil, *Maleuterpes phytolymus* Olliff

The dicky rice weevil is injurious to oranges in Australia, where it attacks the fruit, foliage, and roots. The most serious injury is caused by the adult weevil's feeding on the rind of young fruits. A network of furrows is eaten out of the rind and these turn black by the time the fruit is ripe. The larvae develop in the soil, feeding on the roots (Woodhill and Allman, 1927).

*Control.*—Banding the trees with a sticky material just before the fruit sets is practiced for control.

### Apple Root Weevil, *Leptops squalidus* Boh.

This weevil was recognized in 1928 as a serious pest of citrus in a limited locality in New South Wales. The principal injury is caused by the larvae, feeding on the roots. The adults feed on the young leaves. (Woodhill, 1929.)

*Control.*—Banding the trees with a sticky material is useful in control.

### Weevil, *Hypomeces squamosus* Fab.

This weevil occurs generally throughout the Dutch East Indies, in Asia from Malaya to India. and on Formosa. According to Clausen (1933), it is the most injurious of all leaf-feeding insects on citrus in Malaya. It is especially injurious on young trees, particularly on the pummelo. The beetles congregate in large numbers and eat characteristically shaped sections from

the edges of the young leaves, depositing numerous pellets of excrement on the surface.

WESTERN SPOTTED CUCUMBER BEETLE, *Diabrotica undecimpunctata* Mann.

The western spotted cucumber beetle occasionally attacks citrus trees in restricted areas in California. It feeds on the leaves, blossoms, and young fruits. A skeletonized and ragged effect is produced on the leaves and sometimes on the petals, in the blossom period, and small areas of the young fruits are scarred or gouged out. The beetles come mostly from native grasses and weeds, which upon drying in the spring induce the migration to the citrus orchards. Lemon foliage is only rarely attacked. The beetles are greenish with twelve black spots on the elytra or wing covers. The larvae live on the roots of various plants.

A related species, the banded cucumber beetle, *Diabrotica balteata* Lec., is commonly found on citrus in association with *D. undecimpunctata*, and causes similar injury.

*Control.*—When necessary, the beetles of both species may be satisfactorily controlled by dusting with a 50 per cent cryolite dust or by spraying with cryolite, using 3 pounds per 100 gallons of water. DDT is also effective in control, but its general use cannot as yet be recommended.

STRIPED CUCUMBER BEETLE, *Diabrotica vittata* (F.)

The striped cucumber beetle attacks citrus trees in Florida and other Gulf states. It is similar to the western species in its attack on citrus and in its life history. It does not thrive in sandy soils in Florida and hence is not important where most of the citrus is grown in that state. It occurs in injurious numbers in the Satsuma belt and in the Everglades (Watson and Berger, 1937).

## SNAILS

In parts of California, particularly in coastal localities, the European brown snail, *Helix aspersa* Müller, is an important pest on citrus. Formerly the white snail, *Helix pisana* Müller, was also important, but it has been eradicated (Basinger, 1927). This species is widely distributed over Europe and Africa, where it attacks citrus. Slugs of several species are present in citrus orchards, but they are not considered important.

EUROPEAN BROWN SNAIL, *Helix aspersa* Müller

This snail is widely distributed over the world. In California, in certain seasons, it causes serious damage to citrus. All stages of the snail eat holes in the leaves and make shallow pits in the fruit (fig. 242). They feed principally during periods of high humidity, and when not feeding they usually congregate on the trunk and larger limbs of the tree.

*Life history.*—The spherical white eggs are laid in masses in the ground at a depth of 1 or 2 inches. Since these snails are hermaphroditic, after fertilization any individual may lay eggs. About two years are required for their complete development (Basinger, 1931).

*Control.*—The most commonly used method of control is to apply to the tree, by hand or by a power blower, a bait of calcium arsenate and bran. Or, the bait may be broadcast on the soil beneath the trees. About ½ pound per tree is applied, irrespective of the method of application. The commonly used formula is 6 pounds of calcium arsenate per 100 pounds of coarse-

Fig. 242. Injury caused by brown snail, *Helix aspersa* Müller, on orange fruit and foliage. (Photo by C. O. Persing.)

flaked bran. The calcium arsenate and bran are mixed together dry, and enough water is added to moisten the bait. Freshly pressed orange pulp, a citrus by-product, may be used with calcium arsenate instead of bran (Lewis and LaFollette, 1942). Metaldehyde baits are also used. Best results are obtained by placing this material in small piles on the ground around the tree, using from ⅓ pound to ½ pound of the bait per tree. A mixture of calcium arsenate and metaldehyde in baits is apparently no more effective

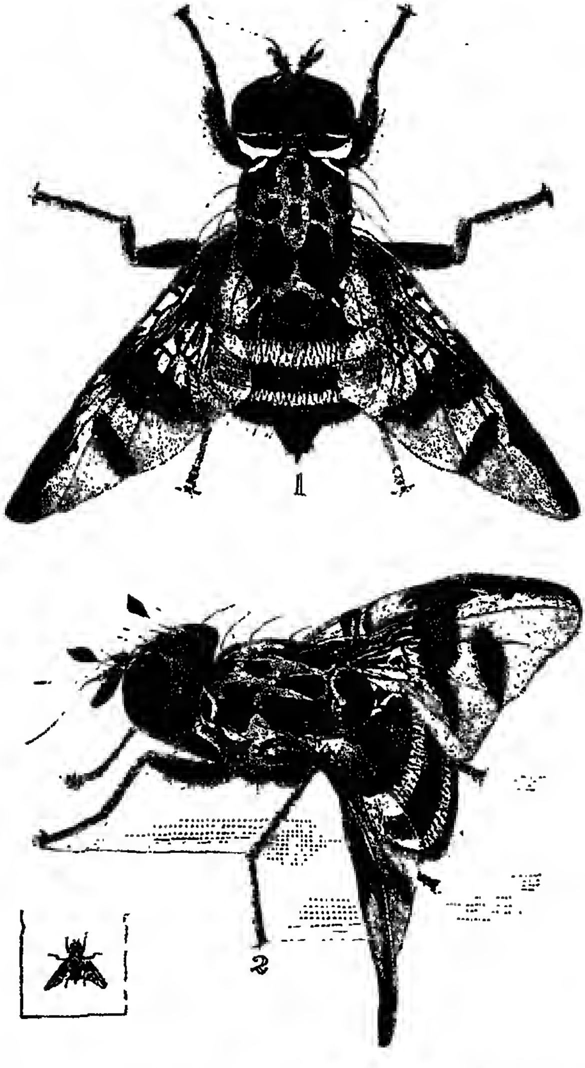


Fig. 243. Mediterranean fruit fly, *Ceratitis capitata* (Wied.). Female, *above;* male, *below.* Characteristic position of wings is shown in lower figure. (After Quayle, 1929*b*, pl. 1.)

than either of the materials used alone. Sprays of tartar emetic and sugar—2 pounds tartar emetic and 4 pounds white or brown sugar per 100 gallons water, 3 to 4 gallons of this mixture being sprayed uniformly on the outer parts of the tree—afford effective results in killing the small and half-grown snails particularly (Persing, 1944). Treatment with any material for snail control should be made when the snails are active, which is in warm, damp weather.

## Group III

Fruit flies (below) and moths (p. 760) the larvae of which cause injury by feeding entirely within the fruits.

### FRUIT FLIES

At least seven species of fruit flies are important pests of citrus in various countries, the Mediterranean fruit fly being the most widely distributed though not everywhere the most destructive. At present (1948), only one species, the Mexican fruit fly, is known to occur sporadically in the United States.

#### Mediterranean Fruit Fly, *Ceratitis capitata* (Wied.)

The Mediterranean fruit fly is an important pest of citrus in the Mediterranean region, South Africa, and Australia, where conditions are similar to those of much of the citrus-growing areas of California. It is also important in Brazil. The adult fly is a little smaller than the house fly. There are two white bands on the yellowish abdomen, black areas on the thorax, and yellow, black, and brown markings on the wings (fig. 243). The wings are normally held in a drooping position.

*Life history.*—The eggs are white, 1/27 inch long, and pointed at each end. They are deposited in a cavity in the rind or beneath the skin of the fruit (fig. 244). The larva, when fully grown, is a little more than $\frac{1}{4}$ inch long and ordinarily of a cream color. It is sluggish in its movements, but when fully grown it has the habit of arching its body and from this position is capable of springing as far as 4 or 5 inches. The posterior spiracles may be seen as six oval-shaped, brown structures. They are arranged in two groups of three, set opposite one another, and are flush with the surface rather than on the end of short stalks as in certain dipterous scavenger larvae. The larvae burrow directly into the pulp of citrus fruits and remain for 10 days to 3 weeks, when they go into the soil for pupation. The pupa somewhat resembles a swollen grain of wheat in appearance. It is of a straw to dark-brown color and transversely ringed. The adult fly, upon emerging, feeds on fruit and plant juices for several days before depositing eggs. This is the vulnerable period in the life cycle, when it may be killed by a poisoned-bait spray.

There are more than 100 different hosts, but the preferred fruits are the peach, nectarine, orange, grapefruit, apricot, and pear. These are not attacked until a certain stage of maturity is reached. Infested fruits are detected by a small slit in the surface, which afterward enlarges as the larvae continue feeding.

*General considerations.*—Conditions favorable to the fruit fly are found in regions of mild winters and where there is a sequence of host fruits (Quayle, 1938*b*), for example, in much of the citrus area of the Mediterranean Basin, South Africa, and Australia. Favorable conditions also occur in California and the Gulf states of the United States: but this fruit fly is not now known to exist in these areas. An outbreak of the fruit fly did occur in Florida, however, in 1929. A vigorous campaign eliminated the fly almost within the same year; there was one light infestation in 1930 (for a full account of it see Newell, 1931), but the fly has not been found in

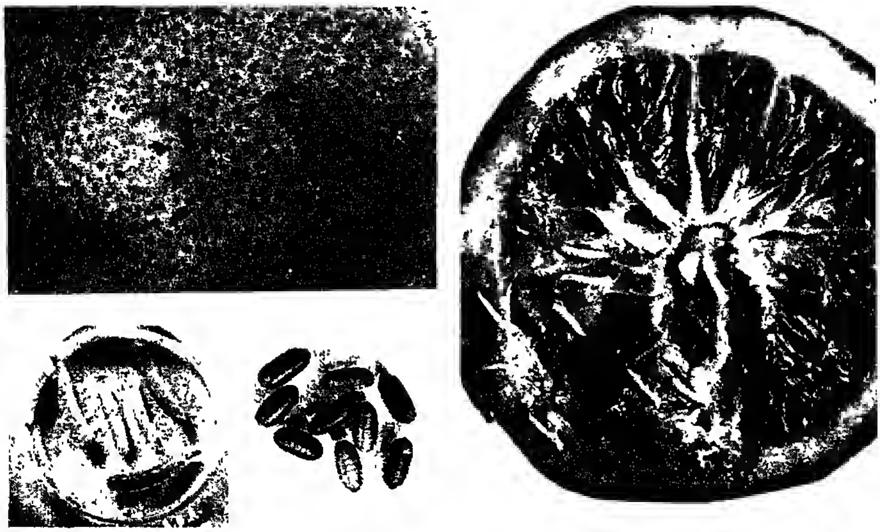

Fig. 244. Mediterranean fruit fly, *Ceratitis capitata* (Wied.). *Above*, holes indicating egg cavities in peel of grapefruit; *below*, larvae on *left* and pupae on *right* (after Wooten); *extreme right*, section of orange showing larvae and injury caused by their feeding.

Florida since. Considering the wide distribution and the extent of attack, particularly on grapefruit, the campaign against it was one of the most successful eradication campaigns in the history of economic entomology.

The Mediterranean fruit fly is not so serious a pest on citrus fruits as on some of the deciduous fruits, such as the peach, because in the infested areas most citrus fruits mature in the winter and it is only the mature fruits that are subject to attack by the fly. At Valencia, Spain, for example, the fly begins to attack some of the early-maturing oranges in October, November, and December. By December the cold weather causes the (adult) fly to disappear, and it does not reappear again until the following June. When the fruits become fully mature, therefore, from December to June, the fruit fly in the Valencia section is inactive. When it becomes active again, almost all the fruit has been harvested. In some of the warmer parts of Spain, however, there is a slight attack of fruit fly in the spring before

all the fruit has been harvested. In the eastern Mediterranean basin—in Egypt, for example—the fruit fly is more or less active throughout the winter months, and consequently there is a more severe infestation of the fly under conditions obtaining in Egypt than under those obtaining in Valencia. In the Mediterranean area, only a small amount of summer-maturing citrus fruit is as yet produced. Summer-maturing fruits could not be grown successfully in areas where the Mediterranean fruit fly occurs unless control measures were resorted to. Valencia or summer-maturing oranges are grown in South Africa and in Australia, but they do not remain on the tree so long through the summer and fall in those regions as they do in California; consequently the injury caused by the fly is less in those countries than it probably would be in California if the fruit fly should become established in this State. Of the citrus fruits the grapefruit seems most susceptible. The lemon is rarely attacked and is of no economic consequence as a host. The fly has been found in the lemon only when the fruit was more or less broken down by decay. It was formerly held that the larva of the Mediterranean fruit fly could not exist in the lemon because of that fruit's acidity; but it has been shown that if larvae are taken in any stage from other fruits and placed in a green lemon, development will continue without interruption (Quayle, 1914).

*Control.*—In the countries around the Mediterranean, traps and lures were for many years resorted to, in attempts to capture the adult flies; but such means of control are less satisfactory than the bait sprays now in general use. The original Mally bait spray, as used in South Africa, was compounded as follows: arsenate of lead, 5 pounds; sugar, 60 pounds; water, 100 gallons.

The bait used in the Florida campaign of eradication was: arsenate of lead, 4 pounds (later reduced to 2 pounds); crude brown sugar, 25 pounds; molasses, 5 gallons; water, 100 gallons. Research in connection with the Florida campaign showed that copper carbonate was a satisfactory substitute for lead arsenate in the bait spray (Miller and McBride, 1931).

In South Africa, control measures employ the use of indicator traps, containing a lure of "Clensel" or of terpinal acetate, which serve as a guide to the timing of applications of the poison bait. The bait used is: sodium fluosilicate, 1 ounce; white sugar, 2 pounds; water, 4 gallons. About 12 ounces of this bait mixture is syringed over each tree in such a manner that it is present on the leaves in small droplets. When large trees are treated, the material is applied from four directions. Orchard sanitation is also recommended (Naudé, 1942*b*).

### Mexican Fruit Fly, *Anastrepha ludens* (Loew)

The Mexican fruit fly is an important pest of citrus, mangoes, and other fruits of Mexico (Crawford, 1927). It also occurs in Central America. About 1903 it became established near Brownsville, Texas, but apparently it was eliminated there in 1905 by freezing weather. In 1927 it was again found in the Rio Grande Valley of Texas, and an eradication campaign was

undertaken by the U. S. Department of Agriculture (Mackie, 1928). Apparently it was eradicated from Texas several times in the ensuing decade, only to reappear principally by natural spread from Mexico. The fact that this species can thrive in the lower part of Texas is a reasonably certain indication that it could become established in parts of citrus areas in California; it has not yet been found, however, in this State.

The adult of the Mexican fruit fly is larger than the house fly and has conspicuous markings of yellow or brown, or of both colors, on the body

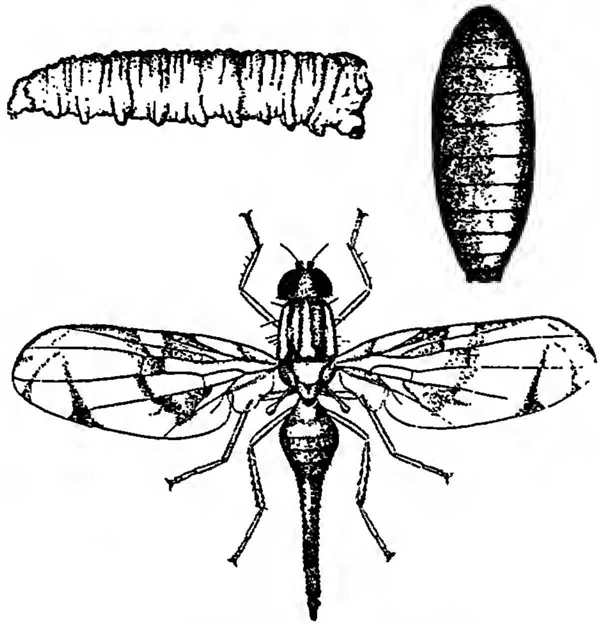

Fig. 245. Mexican fruit fly, *Anastrepha ludens* (Loew): larva, pupa, and adult. (After Quayle, 1938*b*; courtesy Comstock Pub. Co.)

and wings (fig. 245). The female is especially conspicuous because of the long, slender projection terminating the abdomen in which is contained the organ for piercing fruits in order to deposit eggs in them.

An exhaustive study of this species has been made in Mexico by A. C. Baker and his co-workers in the U. S. Department of Agriculture (see Baker *et al.*, 1944).

*Control.*—In the eradication campaign in Texas, measures employed successfully were removal of all other hosts than citrus, maintenance of a host-free period with relation to the presence of citrus fruits in a susceptible stage, trapping, and poison-bait spraying. An additional regulatory measure is heat sterilization of the fruit for interstate shipment. According to Friend (1946), "Fruit flies are occasionally found in valley orchards during the latter part of the fruit year, but loss due to these pests is very small."

### South American Fruit Fly, *Anastrepha fraterculus* (Wied.)

*Anastrepha fraterculus* (Wied.) was formerly known as the West Indian fruit fly. However, this species is now known to be native to South America (Stone, 1942; Baker *et al.*, 1944), where it attacks the sweet orange. The West Indian fruit fly is *A. mombinpraeoptans* Sein. It occurs commonly in the West Indian region, but is not listed as attacking the sweet orange, although the grapefruit and the sour orange are listed as hosts (Stone, 1942). An interesting complex of species in the genus *Anastrepha* occurs in Mexico, the West Indies, and South America; the excellent studies of Stone (1942) and Baker *et al.* (1944) on its morphology, biology, and host relationships have contributed much valuable information about it. The South American fruit fly is of importance on citrus in Brazil, Argentina, and Peru, and possibly elsewhere on that continent. It was introduced into the Azapa Valley of Chile apparently from Peru, but was ultimately eradicated in Chile as the result of a vigorous campaign extending over a period of ten years.

The general aspects of the biology and control of this fruit fly are similar to those given for the Mediterranean fruit fly.

### Natal Fruit Fly, *Pterandrus rosa* (Ksh.)

The Natal fruit fly is a little larger than the Mediterranean fruit fly, but in all essential respects the life histories of the two are similar. The Natal fruit fly, which attacks oranges in certain regions of the Union of South Africa, attacks other fruits in preference to citrus, and is a serious pest of such fruits in certain parts of Natal.

*Control.*—Essentially the same lures and poison baits are used in control of the Natal fruit fly on citrus as are used against the Mediterranean fruit fly. Studies of these means of control have been conducted by Ripley and Hepburn (1929*a*, 1929*b*, 1931, 1935).

### Queensland Fruit Fly, *Strumeta (Chaetodacus) tryoni* Frog.

The Queensland fruit fly is of importance on citrus in Queensland; however, it is much more important on other fruits (Jarvis, 1926). The general biology of the species is similar to that of the Mediterranean fruit fly. Usually, the late-hanging Valencias are most subject to attack by it. Where the female has punctured the rind and deposited eggs, or has inserted the ovipositor into the rind without depositing eggs, there may be characteristic "stings" (New South Wales Dept. Agric., Entom. Branch, 1945). As a result of these "stings," on lemons particularly, there is a gummy exudation and decay often occurs.

*Control.*—Proper orchard sanitation, that is, the collection and suitable disposal of fallen fruits, is essential to success of the control program, which also includes the application of poison baits on the trees. The poison baits are: sodium fluosilicate, 2 ounces; white sugar, 2½ pounds; water, 4 gallons. Tartar emetic may be substituted in equal amounts for the sodium fluosilicate.

### Japanese Orange Fruit Fly, *Dacus tsuneonis* Mikaye

The Japanese fruit fly occurs only in part of the island of Kiushu, where it is an important pest of oranges. Apparently it is a native insect (Clausen, 1927).

*Control.*—Infested fruits are collected and destroyed, and the flies also are collected, under the supervision of government officials (Clausen, 1927).

### Formosan Fruit Fly, *Chaetodacus ferrugineus* var. *dorsalis* Hendel

This fruit fly was considered by Clausen (1933) to be the most common and widely distributed species of fruit fly attacking citrus in tropical Asia. He recorded it from Formosa, the Philippine Islands, Burma, and India. In Formosa, according to Shiraki (1934), it is usually a very minor pest. In May, 1946 (Pemberton, 1946), there was found in several of the Hawaiian Islands an introduced species of fruit fly, *Dacus dorsalis* (Hendel), which is commonly referred to as the mango fly or the mango fruit fly (fig. 246). At present it is not known whether this is the same species as the Formosan fruit fly. According to Holdaway *et al.* (1947), the fly occurs on the five main islands of the Territory. It is known to attack thirty-six different fruits in Hawaii. Although it attacks citrus there, it is much more abundant on other hosts, such as the mango, avocado, papaya, banana, guava, and fig, among others.

## FRUIT-INHABITING LARVAE OF MOTHS

There are a number of species of moths the larvae of which feed and develop entirely within citrus fruits. Two of these species in particular are important pests abroad.

### False Codling Moth, *Argyroploce leucotreta* Meyr.

The false codling moth is one of the important pests of citrus in the Union of South Africa and in Rhodesia (Gunn, 1921; Ford, 1934). It is a native insect that has adopted citrus for a host. It is similar in appearance and in habits to the true codling moth, *Carpocapsa pomonella* (Linn.), a world-wide and important pest of pome fruits. The eggs are deposited mainly on the orange fruit, but some are also placed on the leaves and twigs. As many as thirty eggs may be deposited on one fruit. Upon hatching, the larva enters the fruit, burrowing directly toward the center. It feeds entirely within the fruit and completes its development in about thirty-five days. Immature and even very young fruits are subject to infestation. A characteristic of the burrow in the fruit is the presence of frass, which distinguishes it from the burrow made by larvae of the Mediterranean fruit fly. The feeding of the false codling moth larvae causes the orange to color prematurely, and to drop prematurely also. Premature coloring induces earlier attack by the Mediterranean fruit fly. Pupation occurs in the soil. There are three generations in a year.

*Control.*—All fallen fruits should be collected and destroyed at least once a week from November until the crop is picked. Also, the prematurely col-

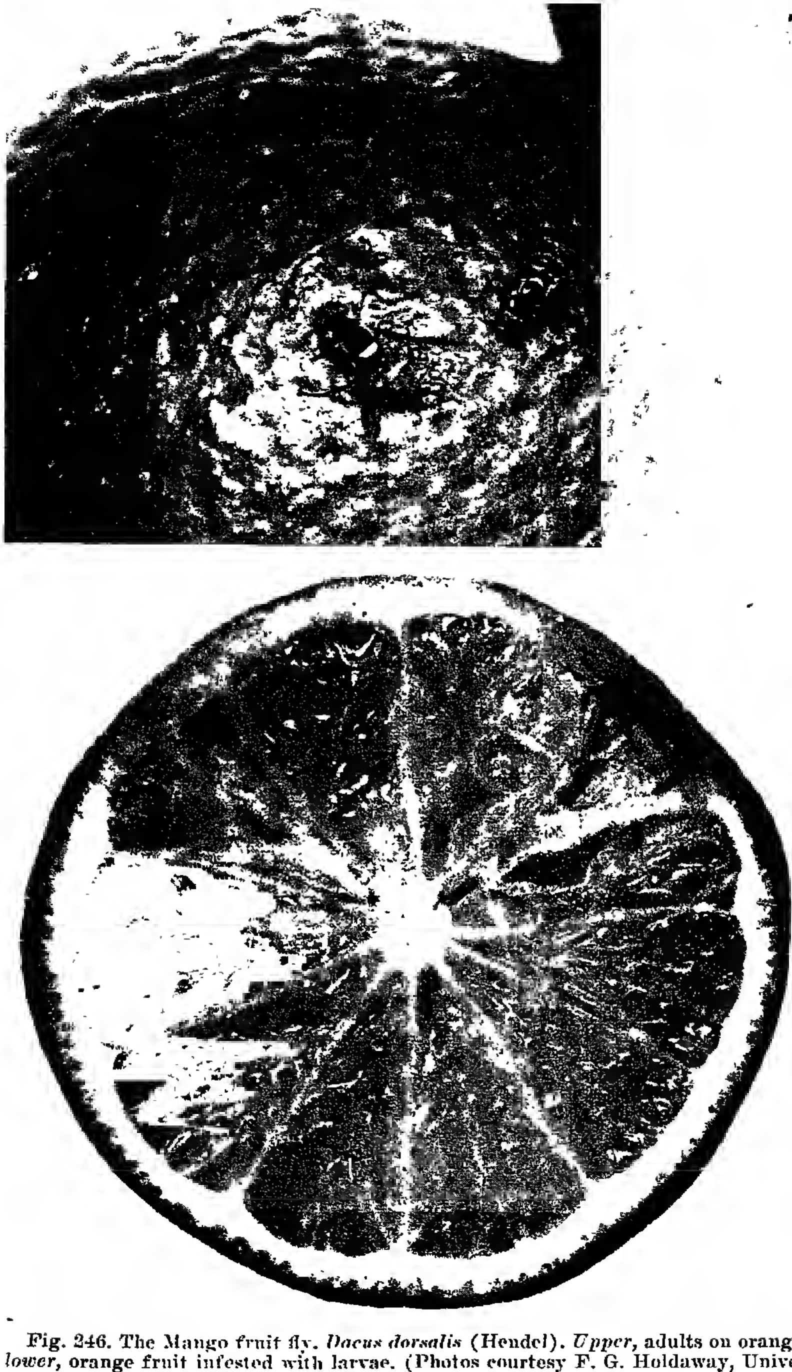

Fig. 246. The Mango fruit fly, *Dacus dorsalis* (Hendel). *Upper,* adults on orange; *lower,* orange fruit infested with larvae. (Photos courtesy F. G. Holdaway, University of Hawaii.)

ored fruits should be picked off the trees. It is essential that infested fruits be disposed of in such a manner that no larvae may escape. The fruits should be buried deeply in the ground, so that no fruit is less than two feet from the surface of the soil, or they should be completely submerged in water for at least seven days (Naudé, 1942*a*).

### Moth Borer, *Citripestis sagittiferella* Moore

The moth borer occurs in Malaya and the Dutch East Indies. According to Clausen (1933), it is by far the most injurious of all the insects that attack citrus in tropical Asia. The orange, lemon, lime, and pummelo are attacked, the pummelo being most susceptible. Infestations on pummelo may be complete, with loss of the total crop.

The small scalelike eggs are deposited singly or in small groups on fruit of any size. Upon hatching, the larvae penetrate the rind, and during the first instar feed on the rind only. They develop subsequently within the pulp of the fruit, throughout which they make their tunnels, lining their burrows with silk webbing. Frass is pushed out to the surface of the fruit; when the pummelo is infested with a rather large number of larvae, it may accumulate at the opening in amounts that hang for an inch or more. The life cycle from egg to adult is from 23 to 30 days. When the larvae are mature, they leave the fruit and enter the soil beneath the tree, where pupation occurs within a cell (Clausen, 1933).

*Control.*—Pagden (1931) suggests the use of stomach-poison spray and the collection and destruction of the infested fruits, or the collecting and caging of the fruits in such manner that the parasites may escape from the cage.

Bagging the pummelo fruits to prevent infestation is practiced; however, it is impractical to bag the smaller fruits such as the orange, lemon, and lime (Clausen, 1933).

### Navel Orange Worm, *Myelois venipars* Dyer

The navel orange worm is not considered of importance as a pest of citrus anywhere. Larvae of this insect may be found in Arizona, southern California, and Mexico, feeding within partly decayed navel, Valencia, and seedling oranges. It is typically a scavenger insect, so far as it infests citrus fruits (Glick, 1922; Woglum, 1946*a*).

## Group IV

Beetles (below) and larvae of moths (p. 764) which cause injury by boring into the woody parts of the tree or by mining (tunneling) in the bark or leaves.

## BEETLES

In various countries, there are many beetles that bore into the woody parts of citrus trees, but they are rarely of significance. Perhaps the most generally important species occur in the Orient. These are the citrus trunk borer and the citrus bark borer.

### Citrus Trunk Borer, *Melanauster chinensis* Först.

The citrus trunk borer is an important pest of citrus in China, Formosa, and Japan. Clausen (1927) reports it as the most important insect attacking citrus in one section of southern China. As a result of the boring of the larvae in the wood the entire tree may be killed. The eggs are deposited in the bark of the trunk near the ground, and the larvae, upon hatching, bore into the trunk and roots. Only a few larvae may cause the tree to die. In Formosa, Shiraki (1934) indicates that there is one generation per year.

*Control.*—In China, the control method that has been practiced is to insert a wire into the burrow and twist it about until the larva is located and killed. In Japan, the adult beetles are collected by children (Clausen, 1927). In Formosa, the control procedure is to destroy the eggs or grubs and collect the beetles, and to prevent egg deposition by applying a whitewash to the tree (Shiraki, 1934).

### California Prionus, *Prionus californicus* Mots.

This beetle has caused the death of a number of citrus trees in the vicinity of Phoenix, Arizona. Although its attack on citrus is not generally severe enough to justify consideration of the insect as an important pest, the spectacular appearance of the beetle and its feeding on citrus are worth mentioning. The adult is more than 2 inches long and is of a dark, reddish, shiny brown color, with three sharp toothlike projections at the margin of each side of the thorax. The full-grown larva is about 3 inches long and has the appearance typical of a grub. The larvae bore in the trunk just below the surface of the ground. This species commonly attacks ash trees, and the affected citrus trees have been close or near to heavily infested ash trees.

*Control.*—Usually, the infestation of citrus trees is not noticed before they are very seriously affected. Probing for the larvae with a wire is a method used in control.

### Lime-Tree Borer, *Chelidonium cinctum* Guer.

The lime-tree borer occurs only in India, where it is a serious pest of the lime particularly, although it attacks other citrus species also. Injury is caused when the larvae bore into the new growth. The eggs are deposited on the bark of the young growth. On hatching, the larvae enter the twigs and make a spiral tunnel around the twigs and into the pith. The twigs are weakened and readily broken at the point of injury. Removal of infested twigs is the method of control practiced (Murthi, 1922).

### Citrus Bark Borer, *Agrilus occipitalis* Esch.

The citrus bark borer is considered the most important pest of oranges and lemons in the Philippine Islands. When infestations are heavy, young trees may be killed. Injury is caused when the larvae mine (tunnel) under the bark of twigs and branches. The adult beetles eat out areas of characteristic shape from the margin of the leaves. The eggs are deposited in cracks and

injured areas on the twigs and branches. Upon hatching, the larvae mine under the bark, an operation which is early evidenced by the exudation of sap (Clausen, 1933).

*Control.*—Tan (1925) recommended as measures of control the daily collection of beetles, spraying at monthly intervals with lead arsenate or calcium arsenate, and painting the trunk and branches with concentrated lime sulfur to help prevent the beetles from laying eggs.

### Black and Red Leaf Miner, *Throscoryssa citri* Maulik

Black and red leaf miner is the common name for this species of beetle in China, where it is now considered an important pest of citrus. The first account of this insect is given by Clausen (1931) as a result of his studies of it in Assam, India, where it almost completely destroyed foliage on some trees each year. The eggs are deposited mainly on the under sides of new leaves. Upon hatching, the larva enters the leaf tissue and mines in a serpentine pattern, consuming the leaf tissue between the upper and lower surfaces. The larva has the habit of abandoning one mine and beginning another on the same or another leaf. As the result of its feeding in this manner, the entire leaf tissue between the upper and lower epidermal cells may be destroyed (Clausen, 1931). When mature, the larvae go to the soil, where pupation occurs. There is but one generation in a year. The adult beetles feed gregariously, eating irregular areas from the margins of the young leaves.

## LEAF-MINING LARVAE OF MOTHS

There are a number of species of small moths the larvae of which make mines or tunnels in the leaves and green twigs or in the peel of fruits of citrus (fig. 247). In most citrus-growing areas it is not uncommon to note the presence of a conspicuous serpentine mine. With the exception of the mines produced by the citrus leaf miner, *Phyllocnistis citrella* Staint., their occurrence on the leaves and green twigs is of no consequence, and on the fruits only rarely so. However, a small proportion of a grapefruit crop may occasionally be reduced in grade by the presence of these mines.

### Citrus Leaf Miner, *Phyllocnistis citrella* Staint.

The citrus leaf miner is of importance on citrus in the Orient, particularly where, according to Clausen (1931), it may be found in greater or lesser numbers on nearly every tree. It is generally abundant in China, Japan, Formosa, Siam, the Federated Malay States, and India. It is found in other areas of the Orient also, and in Australia and at Capetown, South Africa. The larvae sometimes mine in the green bark of the young growth, but injury is mainly caused when they mine in the leaf between the upper and lower surfaces. The serpentine mine produced is characteristic and conspicuous. As a result of the leaf mining, the leaves curl somewhat as they do from the effects of attack by aphis. According to Kurisaki (1920), the citrus canker (*Pseudomonas citri* Hasse) may infect the tree through the mines of this insect. The small moth deposits the tiny eggs on the lower surface of the leaf. Upon hatch-

ing, the larva enters the leaf, where it remains until mature: it then comes out of the leaf and forms a pupation cell by folding over a part of the leaf margin. There may be six generations in a year.

*Control.*—In India the recommended control is to collect infested leaves and to spray the tree with nicotine sulfate (Hayes, 1945).

## Group V

Ants that cause injury by feeding directly on the tree or by interfering with the work of beneficial insect enemies of citrus pests.

Fig. 247. Mine of *Marmara* sp. in orange. (Photo by D. W. Tubbs.) (Quayle, 1938*b*; courtesy Comstock Pub. Co.)

## ANTS

A number of species of ants are important pests of citrus because they either feed on various parts of the tree or foster an abnormal increase in the populations of many injurious insects that excrete honeydew, such as certain scale insects, mealybugs, and aphids. Ants that are fond of honeydew as food may actually distribute and virtually care for certain species of insects that excrete honeydew. The presence of the ants and their activities in association with the insects they are "tending" often interfere seriously with the attack of parasites and predators of these insects.

### Fire Ant, *Solenopsis xyloni* var. *maniosa* Wheeler

The fire ant has been more important as a citrus pest in Texas than elsewhere in the United States. It is common and abundant in California and

Arizona, where it causes some injury to young trees annually, either in the nursery or in the field. In Texas the ants feed on the bark or young tender branches (Clark, 1931). Observations made in California indicate that the ants are attracted by gum exudations on the bark, upon which they feed; but they also bite away the bark and feed on the cambium. Recently planted trees may be completely girdled in a short time. According to Friend (1946), many thousands of citrus trees in Texas have been killed by the girdling activities of this ant. The nest is commonly made at the base of the tree, and when the ants are abundant the nest is large and conspicuous because of the mounds of soil around the opening. The worker has a yellowish red head and thorax and a black abdomen. This is a pugnacious species that bites and stings when disturbed. The sting produces a burning sensation which accounts for the common name "fire ant."

A related species, *Solenopsis germinata rufa* Jerd., causes injury to young pummelo trees in Malaya (Clausen, 1933). When honeydew from aphids and soft scales is an insufficient source of food, the ants eat the surface tissue of young shoots, causing the death of this growth.

*Control.*—Clark (1931), having studied control of the fire ant in Texas, recommended a syrup containing thallium sulfate as a poison and the appropriate use of calcium cyanide to fumigate the nests. It was well recognized that the use of both these materials is hazardous to human beings, and that improper use of calcium cyanide is hazardous to the trees. Because of the danger to the trees from the use of calcium cyanide for fumigating the colony when the nest is near the crown roots, Friend (1946) recommends frequent inspection during the danger period, that is, during the fall season, and, at weekly intervals, repeated dustings into the disturbed nest of ants, using concentrated pyrethrum (1.3 per cent pyrethrins).

In California, where the ants are not generally so numerous, injury can in large measure be prevented by careful orchard management to prevent gumming of the trees; gumming, as mentioned above, apparently attracts the ants. The use of tree protectors favors the attacks of the fire ant because some protectors, particularly those of dark color, may induce gumming. Moreover, they afford shelter to the ants and obscure the injury so that it is not detected by the grower. Whitewash may be used in place of the protectors. Metcalf and Rogoff (1946)[1] obtained excellent control of the fire ant in citrus nurseries by means of a dust containing 3 per cent chlordan.

### Little Fire Ant, *Wasmannia auropunctata* (Roger)

In citrus orchards in parts of the east coast of Florida, the little fire ant, which is present on the trees in order to obtain honeydew from other insects, is a serious annoyance to workers in the orchard. According to Osburn (1945), the ants are sometimes so abundant that it is impossible for workers to pick fruit, or prune or spray trees, without becoming covered with them and suffering many stings. Most persons suffer noticeable irritation from a single sting.

[1] R. L. Metcalf and W. M. Rogoff, unpublished data, 1946.

*Control.*—Osburn (1945) obtained good control with DDT–fuel oil emulsion, which is sprayed on the trunk and larger limbs of the trees. A single treatment afforded effective control for at least four months. The present recommendation is the use of DDT wettable powder at a dosage of ½ pound actual DDT per 100 gallons of water, applied only on the trunk and main branches two weeks before picking time. (For further details see Florida spray-and-dust schedule, p. 799.)

### *Myrmicaria brunnea* Saund

Clausen (1933) reports that in Ceylon, when the large subterranean nests of this ant are present in plantings of young citrus trees, much damage is done. The ants bite off the tips of the buds and congregate in large numbers to feed on the exuding plant juices. They also destroy the surface tissue of young shoots and make holes in the younger leaves.

### Leaf-cutting Ants, *Atta* Species

The leaf-cutting ants are important pests of citrus in Mexico, Central and South America, and the West Indies. One species, *Atta texana* Buck, is of importance in the Texas citrus-growing areas, particularly in plantings near brush land. Members of the worker caste of these ants cut pieces out of the leaves and take them to their nests, where they are used as a compost for the culture of a fungus which is used for food. (For complete discussion of this subject see Wheeler, 1907.) Citrus leaves are favored materials for this purpose, and since these ant colonies are enormous in size and number of inhabitants, many citrus trees may be completely defoliated in a single night.

In addition to *Atta texana* Buck in Texas, other species that are important as citrus pests are: *A. mexicana* Smith, in Mexico and Central America; *A. sexdans* Linn. and *A. cephalotes* Linn., in Central America and Brazil, also *A. laevigata* F. Sm. in Brazil; *A. cephalotes* Linn. and *A. octospinosa* (Reich) Em., in Trinidad; *A. insularis* Guerin, in Cuba; and, in Argentina, several *Atta* species—but *Acromyrmex lundi* (Guer.) Rog. is considered more important there than any of the *Atta* species.

*Control.*—Destruction of the colonies is the most feasible method of control. Because the nests are very large, and differ in kind for different species, the problem of annihilation of the entire colony by cyanide fumigation is a difficult and unreliable procedure. Carbon bisulfide is commonly used in many places with success; however, one of the commonest methods of control used in Brazil is fumigation of the nests with the gases produced by burning sulfur and white arsenic on glowing charcoal in a special apparatus (Autuori, 1942).

### Argentine Ant, *Iridomyrmex humilis* Mayr

The Argentine ant is a native to South America and was introduced into the United States at New Orleans about 1888. It appeared about 1902 in California, where it has become important because, in its "tending" of certain scale insects, mealybugs, and aphids, for the honeydew they excrete which it uses as food, it affords some protection to these insects from their parasites

and predators. There is also evidence that the ants actually carry some of the insects to other parts of the infested tree, or possibly to other trees, hence aiding in the distribution of certain pests on citrus (Horton, 1918*a*). In California, the Argentine ant is of most importance in relation to the biological control of unarmored (or soft) scales and mealybugs. (For further details see chap. xii; also the section, "Soft Scale," p. 724.)

The Argentine ant occasionally feeds on the blossoms, but this injury is considered insignificant. Sometimes the ants feed on freshly made wounds, and this may have a bearing on the greater incidence of certain plant diseases (Horton, 1918*a*).

The worker ants are brown in color. They travel in well-defined lines to and from the nest, particularly when going up and down the tree trunk. When one is crushed, there is no perceptible odor. In California the season of greatest activity usually extends from late February through October.

*Control.*—The standard means of control of this ant in citrus orchards is the use of poison baits which when carried to the queen in her nest destroy the source of the colony. The formula effectively used in a large-scale cleanup campaign in Los Angeles County, California (Ryan, 1928), which is essentially the United States government formula, and the method of making it, are as follows: Water, 11 pints; tartaric acid, ¼ ounce; benzoate of soda, ⅛ ounce; granulated sugar, 12 pounds; chemically pure sodium arsenite, ¾ ounce; strained honey, 2 pounds. Heat the water until lukewarm. Add the tartaric acid and stir until dissolved. Add the benzoate of soda and stir until dissolved. Slowly add the granulated sugar, stirring constantly until dissolved. Note the exact height of the liquid in the container, cover, and boil slowly for 40 minutes. Add water to equal the amount evaporated at the end of each 20 minutes. To 1 pint of lukewarm water add the sodium arsenite and stir until completely dissolved; then add this to the syrup and stir well. Finally, stir in the honey.

This bait was formerly placed in paraffined paper cups which were attached to the trunk of the tree, but subsequently aluminum cups were used. There have been many modifications in the type of dispenser used for ant poisons, and some modification in the composition of the poison bait. Proprietary preparations of baits and dispensing containers are now most commonly used in California.

DDT and chlordan show promise of usefulness for control of this ant in citrus orchards (Basinger and Metcalf, 1946).[1]

### THE GRAY ANT, *Formica cinerea* var. *neocinerea* Wheeler

The gray ant is a native California species and is important in citrus orchards because it interferes with the activity of parasites and predators on mealybugs and unarmored scale insects. It is of interest to note that the Argentine ant is dominant in abundance over the gray ant when both species occur in the same orchard; in fact, the Argentine ant virtually drives the gray ant out of an orchard.

[1] A. J. Basinger and R. L. Metcalf, unpublished data, 1946.

The gray ant is relatively large, that is, about 1/4 inch long, and grayish in color. Locally it is often referred to as the "crazy ant" because of its jerky and seemingly uncoördinated manner of moving about.

*Control.*—This species is not always readily controlled. Best results have been obtained by doubling the quantity of sodium arsenite in the formula used for control of the Argentine ant (see above). DDT and chlordan show promise of usefulness for control of the gray ant in citrus orchards (Basinger and Metcalf, 1946).[1]

### Cultured Citrus Ant, *Oecophylla smaragdina* Fabr.

The cultured citrus ant is generally distributed in tropical Asia and is actually cultured by citrus growers in southern China. Even though this ant utilizes citrus leaves to make its nest, it is not considered a pest, but rather a beneficial insect since the purpose of the colonization is to control leaf-eating insects on the trees. Growers place bamboo rods from tree to tree so that the ants may readily move about in the orchard. The ants are relatively large in size, of light brown color, and move very rapidly. They are pugnacious and will attack and kill caterpillars and other large insects. They also attack man, with painful results.

The actual value of these ants in protecting citrus from injury by other insects has not been fully determined.

The biology of this ant is very unusual and interesting (for details see Groff and Howard, 1924). The nest is about 8 to 10 inches in diameter and somewhat spherical in shape. It is made by drawing the leaves together and sewing them in place. For the sewing the adult employs its larva as a shuttle, using the silk secreted by the larva as thread.

## CITRUS PEST CONTROL

### CONTROL IN CALIFORNIA

The control of insect and mite pests[2] in California citrus orchards is one of the most highly specialized and expensive operations in the production of the crop; however, advice and help are usually available. The county agricultural commissioner's office has the responsibility of inspecting orchards to determine pest conditions, recommends treatments for growers to use, and supervises generally the application of the pest-control materials. Representatives of the agricultural extension service of the University of California in each county coöperate with the respective agricultural commissioner's staff in the educational aspects of citrus pest control. In addition, there are other organizations concerned with pest control in citrus orchards, such as coöperative and private citrus marketing organizations, coöperative and private pest-control organizations, research, development, and marketing agencies of industrial chemical concerns, and private advisory services. These agencies coöperate with the Division of Entomology and the Division

[1] A. J. Basinger and R. L. Metcalf, unpublished data, 1946.

[2] Information on the control of each species is included with the discussion of that species elsewhere in this chapter.

of Biological Control of the University of California Citrus Experiment Station, and with the laboratory of the U. S. Bureau of Entomology and Plant Quarantine at Whittier, the principal function of which is research.

The actual operations for pest control are carried on largely by coöperative nonprofit organizations and commercial pest-control companies which contract to do the work. However, individual growers or orchard companies having sufficiently large acreage to warrant the capital expense usually have their own equipment for spraying and dusting and, sometimes, for fumigating also. In addition to chemical control operations, some of the coöperative pest-control organizations operate insectaries for the propagation of beneficial insects. Insectaries are also operated by the agricultural commissioner in several counties, by private individuals, and at least one by a large orchard company, the Limoneira Company.

Among California citrus growers there are several rather exceptional organizations for combating citrus pests. The oldest of these, and perhaps the most noteworthy in accomplishments, are the Ventura County Citrus Protective League (Hardison, 1941) and the Fillmore Citrus Protective District (Anon., 1947*b*). Both these organizations are in Ventura County and both have been continuously in operation for more than twenty-five years. They are unincorporated voluntary coöperatives whose objectives are the suppression and (or) eradication of certain serious citrus pests, particularly the California red scale. Whenever an infestation of red scale is found, eradicatory measures are employed. Only one-third the cost of these treatments is borne by the owner of the infested property; the other two-thirds is borne equally by the shipping organization of which the grower is a member and by the protective league or the protective district, as the case may be. Funds for the operation of these organizations accrue from assessments upon all members, the assessments being fixed in accordance with numbers of trees. The accomplishments of these organizations have been of inestimable value to the districts concerned. Besides the voluntary type of district organizations for citrus pest control mentioned above, there are districts legally authorized under the Citrous Pest District Control Act, a legislative measure enacted in 1939 and included in the Agricultural Code of California (California, *Laws, Statutes,* etc., 1944). The purpose of this act is "to make available a procedure for the organization, operation, government and dissolution of districts for the more effective control and eradication of citrous pests." These districts are formed within the county. They are operated under the county government and financed by tax assessment on the citrus properties included in the districts. Several of the districts have been formed to combat the California red scale.

### BIOLOGICAL CONTROL

The utilization of parasitic and predatory insects for control of pest species on citrus in California constitutes a very important and highly essential part of the general citrus pest control program. Because a relatively large number of new and promising insecticides are being developed, it is increasingly

apparent that information on their probable adverse effect on the fauna of beneficial insects should be made available before any new material is widely used. Since this large and highly specialized field of biological control is treated fully in chapter xii, further discussion here is unnecessary.

## Fumigation

Fumigation with hydrocyanic acid originated in California in 1886, and ever since has been one of the most dependable methods for the control of scale insects on citrus trees. Soon after its use was begun, generation of the gas was by the "pot system," which consisted in placing water (3 parts by volume), sulfuric acid (1 part by volume), and potassium cyanide[1] (1 part by weight) in an earthenware vessel beneath each tented tree. About 1913, this system was replaced by "machine generation." The machine consisted of a generating and supply chamber mounted on two wheels and drawn by a horse. The generating chamber held the sulfuric acid and water, to which was added the required amount of cyanide solution for each tree. The gas from the cyanide solution was evolved almost instantaneously and was forced by its own pressure through a hose to the tented tree. In 1916 the first tests with liquid hydrocyanic acid (HCN) were made, and the method utilizing HCN in liquid form quickly came into very general use. In California, this method has been used almost exclusively since 1918. (For more complete discussion of fumigation see Quayle, 1938*b*.)

Liquid hydrocyanic acid is manufactured at a central plant and is carried to the orchards in drums of 80 and 100 pounds capacity. From the drums it is transferred into so-called vaporizers, which measure the schedule, vaporize the liquid, and deliver it as a gas under the tree. Liquid HCN is a colorless liquid, boiling at 80° F. and having a specific gravity of 0.70 at a temperature of 65° F. It is very volatile and must be kept at fairly low temperatures to be safe in handling. During hot weather the drums of HCN are kept in a cool place where there is air circulation, and are usually covered with sacking over which water drips. When the HCN is transported by truck during the warmest weather, it is packed in ice as an additional safeguard.

The use of liquid hydrocyanic acid in citrus fumigation, as explained above, is applicable only where there are rather large areas of contiguous plantings of citrus which would justify setting up a plant for manufacturing it. At present, plants are maintained in California, Spain, and South Africa. Liquid hydrocyanic acid may be transported for a considerable distance in specially equipped cylinders, but this method of transport is not extensively used in connection with citrus fumigation. Where liquid hydrocyanic acid is not available, the pot system, the machine-generation method, or fumigation with calcium cyanide dust may be employed. The general procedure for fumigation is similar, irrespective of the method used for generating of the gas. Where the pot system is used, earthenware vessels are placed under each

[1] After 1909, sodium cyanide was used in the proportions of 2 parts by volume of water, 1½ parts by volume of acid, and 1 part by weight of cyanide (51–52 per cent cyanogen).

tent and the water, cyanide, and acid are placed in this generating vessel. Sodium cyanide of 52–54 per cent purity, which is generally employed for fumigation purposes, is used according to the following formula (Woglum, 1911): sodium cyanide, 1 ounce by weight; sulfuric acid, 1½ ounces (fluid); water, 2 ounces. The water is placed in the generating chamber first, then the acid, and finally the cyanide.

Where conditions will permit, the use of calcium cyanide dust is simpler than the pot system of generation. All that is necessary is to distribute the dust under the tent by means of a blower. Sometimes it is simply spread on the ground. The moisture in the air reacts with the calcium cyanide, liberating HCN. The use of calcium cyanide dust is restricted to regions of relatively dry climate. The deposit of calcium cyanide in the presence of considerable moisture causes burning, particularly on lemons. The orange is much less susceptible to burning, but there is greater risk of damage from calcium cyanide in humid areas (Quayle, 1928).

## EQUIPMENT

*Tents.*—The tenting materials now in use in California are of 7- or 8-ounce United States Army duck and 6½ ounce special drill. Usually the special drill is used only for wings of the tent; the central part, where most of the wear occurs, is made of the duck. Nylon tents (Lindgren, Gerhardt, and Vincent, 1947) and gas-tight tents (Lindgren and Dickson, 1943) are now being investigated. Nylon tents have the advantage of light weight, high tensile strength, and about the same gas-holding capacity as tents of 8-ounce canvas. With gas-tight tents, only one-third to one-half the present dosage is used, with the same results; but there is danger to the crew from the HCN liberated as the tents are moved from tree to tree.

The tents are octagonal sheets of different diameters, usually 36, 45, 48, 50, and 55 feet. When buying tents, one should take into consideration the normal growth of the trees for the next four or five years. For trees up to 10 feet in height, 36- to 40-foot tents are used; for trees up to 15 feet, 40- to 45-foot tents; and for trees from 16 to 21 feet in height, 45- to 55-foot tents.

The tents are marked with three parallel lines of figures, starting at 5 or 6 feet from the center of the tent and running toward the two opposite edges. By reading these figures on the tent where they appear at ground level on opposite sides of the tree, the distance over the tree is determined. A tape reading gives the distance around. Once the distances around and over are known, a dosage table is used for determining the number of units of HCN the tree should receive (Woglum, 1923).

*Poles and derricks.*—Two poles, 2 to 2¼ inches in diameter and 14, 16, or 18 feet long, are used for pulling the tents over the trees. Near one end of the poles a rope is attached, which extends about 3 feet beyond the other end. A ring on the tent is placed over the end to which the rope is attached; the other end is sharpened so that the pole will stick into the ground while it is raised, with the tent attached, by means of the rope (fig. 248). For raising tents over very large trees, special derricks are used.

Tent-pulling machines developed and perfected by commercial operators have recently come into use because labor for hand operation has become difficult to obtain (fig. 249). Mechanical tent pullers have practically replaced hand crews in California. Such machines are capable of handling 60 or 75 tents in the 50 to 60 minutes during which the trees are exposed to the

Fig. 248. "Hand pulling" of fumigation tent over orange tree.

gas. Mechanical tent pullers eliminate the heavy labor of hand pulling, reduce the wear and tear on the tents, lessen the hazard of injury to the trees, and increase the number of trees fumigated by a crew in a single night. The operation is illustrated in fig. 250.

PROCEDURE IN CALIFORNIA

In California, fumigation is carried on by coöperative pest-control associations, local citrus associations, commercial operators, or private owners.

Directions to govern the work to be done are in large part determined by the respective agricultural commissioners in the different counties. These

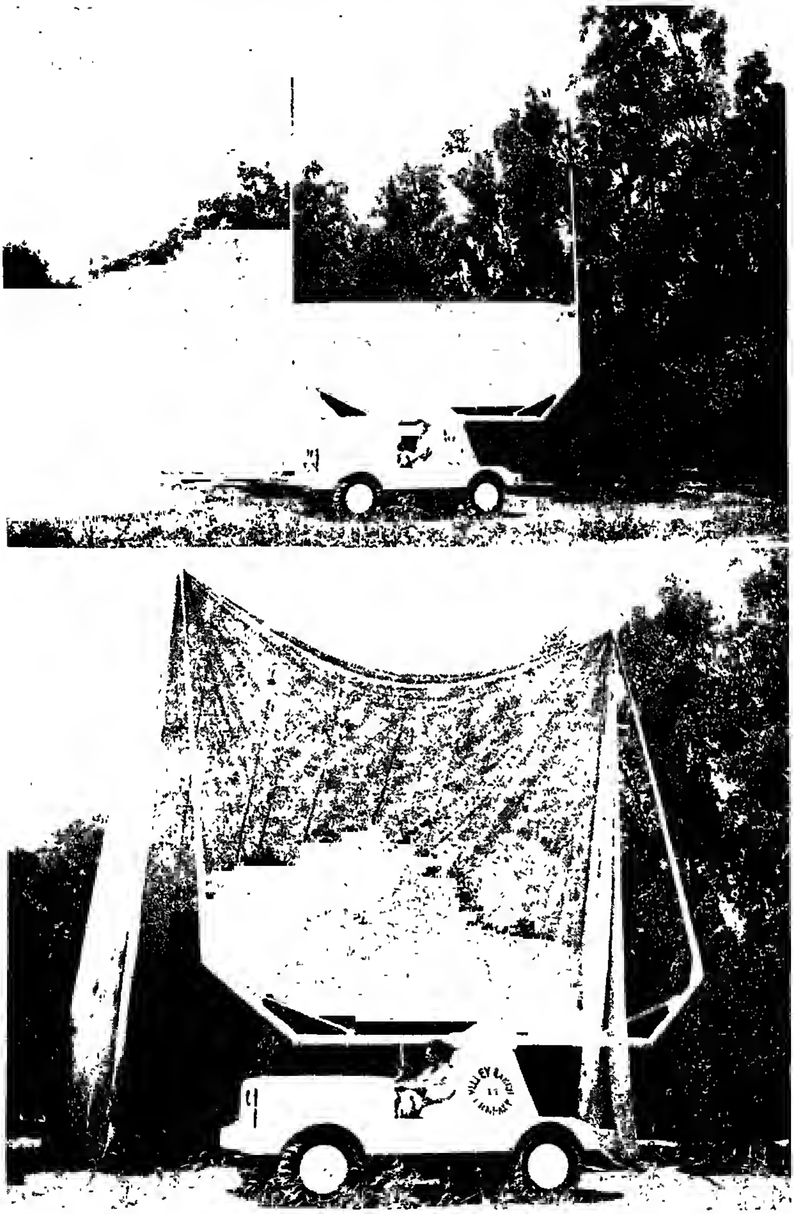

Fig. 249. Mechanical tent puller in operation. (Valley Ranch Co. equipment; photo by R. S. Woglum.)

officials issue licenses to properly qualified operators; determine when treatment is necessary; indicate the range of temperatures, and, more or less, the humidity at which the work should be carried on; advise concerning the schedule and other general regulations of the work; inspect the equipment; and finally, check the results.

At present the gas is applied to the tree by a vaporizer, a machine in which the measured amount of liquid HCN is pumped into coils in a steam boiler in which it is vaporized and from which it is passed through a hose under the tented tree. This is the "hot gas" method of generation, now exclusively

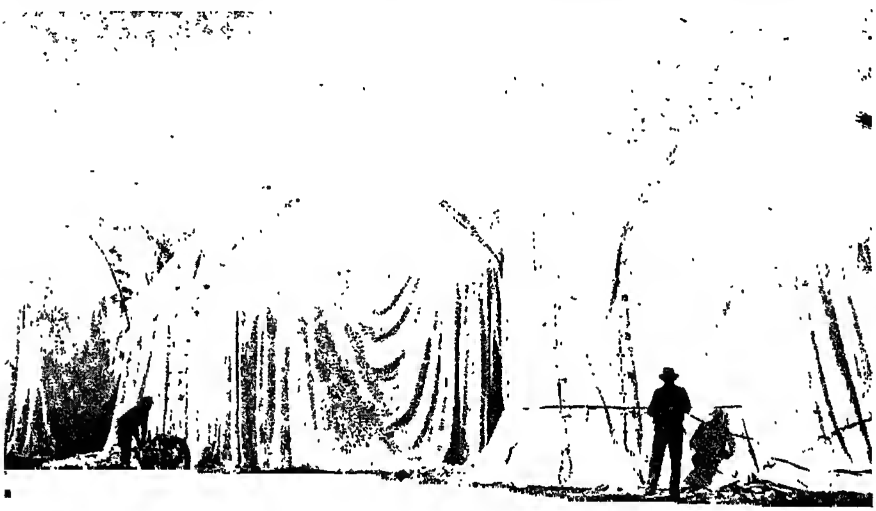

Fig. 250. Fumigating large trees with HCN. Note "marking" on tents; note, also, "taper" (*right*) and "gunner" (*left*) charging tented tree with "hot gas" applicator or "gun." (Photo by A. F. Kirkpatrick.)

used. It results in a rapid diffusion of the gas in the tent and is desirable when fumigation is carried on at the lower temperatures (below 50° F.). The vaporizers are owned and serviced by the companies that supply the HCN, and are lent to the fumigators.

The temperature range at which fumigation is carried on extends from 40° to 80° or 85° F., most of the work being done at temperatures between 50° and 70°. In areas along the coast 70° or 75° is considered the maximum temperature. In the interior, fumigation may be begun at a temperature of 80° to 85°.

The relative humidity cannot be accurately indicated for the practical fumigator. When moisture is visible on the trees, and tents begin to feel moist, these are the most practical indications that it is time to stop fumigation; but practices differ in different areas. In some, fumigation is continued until the tents become wet and too heavy to handle. If the humidity is high,

tents become damp and tighten and hence permit less leakage of gas. But when the tents are wet, they also pick up particles of sand and grit, and these, when the tents are pulled off the trees, abrade the surfaces of fruits; it is here that injury is most likely to occur.

The fumigation schedule is determined with reference to the scale insect for which treatment is to be made, the species of citrus fumigated, the season of the year, and the locality where the fumigation is carried on. The schedules are indicated by the number of cubic centimeters in a so-called unit. Before liquid HCN came into use, the schedules called for a certain number of ounces of sodium cyanide, the amounts being determined by the distance over and around the tree (Woglum, 1909): roughly, for an ordinary-sized tree, 1 ounce of sodium cyanide was required for each 100 cubic feet of space; for smaller trees the schedule called for more than 1 ounce for each 100 cubic feet; and for larger trees, less than 1 ounce per 100 cubic feet. The amount per unit of volume varies because for a smaller tree there is more tent surface in relation to the volume than there is for a larger one, and the amount of tent surface is one of the factors that govern the schedule because the greater the tent surface the greater is the leakage of gas. When liquid HCN came into use, this same general schedule was retained, but instead of indicating the schedule in ounces, the term "unit" was applied as the more convenient one.

In making a comparison of liquid HCN dosage with the older methods in which ounces of cyanide were used, 1 ounce of sodium cyanide (51–52 per cent cyanogen) is equivalent to 20 cc. of liquid HCN of 97 per cent purity. Instead of having different schedules prepared according to the dosage to be given to a grove, as was done under the old system of using ounces of cyanide, when the liquid HCN came into use a single schedule with some modification was adopted and a variation was made in the unit. The ounce was of fixed value, and to vary the dosage a different number of ounces was called for, from different printed schedules. On the other hand, the unit is of variable value, and to vary the dosage the value of the unit is changed. This is done by setting the applicator, or vaporizer, to deliver a different amount of liquid HCN, while the schedule, or the number of units called for, remains unchanged. Consequently, the applicators for the delivery of HCN under the tent can be set to deliver 14, 16, 18, 20, 22, or 24 cc. for each unit, according to the dosage which should be used under the different conditions. If the tree called for 10 ounces of sodium cyanide under the old system, the same tree under the new system of liquid HCN would call for 10 units of liquid HCN; and if 14 cc. was the amount per unit, that particular tree would be given 140 cc. If the amount per unit was 20 cc., the amount of liquid HCN would be 200 cc., etc. There are approximately 640 to 650 cc. in 1 pound of liquid HCN, according to the temperature and degree of purity.

The amount of HCN used on any block of trees may be determined by adding the total number of units given to all the trees and multiplying this by the number of cubic centimeters in the schedule used. That is, on a 20 cc. schedule, the total number of units in the orchard multiplied by 20 cc. will


Fig. 251. Row or "string" of fumigation tents covering orange trees. (Photo courtesy Am. Cyanamid Co.)

give the total number of cubic centimeters used in the grove, and from this the number of pounds may be determined by dividing by 640, the number of cubic centimeters in 1 pound of liquid HCN.[1]

[1] The number of cubic centimeters in a pound of liquid HCN varies with the purity and with the temperature: 640 cc. = 1 pound liquid HCN of 96 per cent purity and at 60° F.

The number of tents in a "string," that is, the number used by one crew of men, depends somewhat upon the size of the orchard to be treated. If the rows in a particular orchard are 30 trees long, 30 tents are placed along one side of the grove and 30 additional tents along about the center row of the grove (except in large groves), 60 tents in all, and in pulling and charging the tents a round trip is made, that is, the operators go up the first row of tents and down the second row (fig. 251). The tents are left on the trees for 50 minutes to 1 hour. At the end of that time the tent is pulled from the first tree in the first row and hoisted over the first tree of the next row, and so on, the last transfer being made to the last tree of the second row of tents. The usual crew consists of four men: two to pull tents, the third to follow up, measuring anad kicking in the edges of the tent, and the fourth to deliver the charge to the tent as called out by the man measuring the tree immediately ahead. Four men are used to pull the tents if the trees are very large. However, when mechanical tent pullers are used, the crew is of five men irrespective of the size of the tree; one man operates the tent puller, two men hook the edge of the tent to the poles, the fourth man measures the tree, and the fifth man operates the vaporizer. Under optimum conditions, with use of a mechanical tent puller, as many as seventy-five tents can be handled by one crew.

### COST

The cost of the fumigation is directly related to the size of the tree, and is usually divided into coverage and cost of the HCN used. The coverage includes cost of labor, wear and tear on the tents, interest on investment, depreciation, etc. When fumigation is done by contract, the fumigator agrees to cover the trees for a certain amount, the cost of the HCN (depending upon the amount used) being added. Prior to 1942, the cost of the HCN was about one-half the total cost of the operation, and the coverage cost the other half. On an average, the cost of fumigating in California prior to 1942 was approximately 40 cents a tree, 20 cents representing the cost of the HCN and 20 cents the coverage. Since 1942, labor costs have increased but the cost of HCN has not; hence at present it costs about 50 cents to fumigate an average-sized tree—20 cents for gas and 30 cents for coverage.

### PRECAUTIONS AGAINST INJURY TO TREES

A number of precautions are to be taken in order to avoid injury to the tree and at the same time to make the fumigation effective in killing the scales. In the first place, the season of the year must be considered. Generally speaking, the fumigating season begins early in July and continues into the following March. Fumigation cannot be practiced from the time the oranges set until they are about ¾ inch to 1 inch in diameter, without undue risk to the fruits.

The summer fumigation work begins with navels in July since normally they are more advanced than Valencias. The navel and Valencia trees are about equally resistant; however, most of the Valencias are in orchards in the coastal area, where there is more danger of injury than in the interior.

The ordinary dosage cannot be used on such varieties as the St. Michael and Homosassa, the fruits of which are very susceptible to injury.

The lemon is the most resistant of all of the citrus species. The fumigating season for the lemon is longer than that for the orange because the young lemon fruits, unlike the young orange fruits, do not all appear at one time, and because lemon fruits of all ages are more resistant than small oranges to injury from the gas. The lemon tree may be fumigated at almost any time of the year.

On the other hand, the insect pest present may definitely limit the time of fumigation. The black scale is not effectively controlled by fumigation except when in its younger stages; consequently, fumigation must be restricted to a time when these stages occur if it is to be effective. The citricola scale requires a still narrower time restriction since it becomes resistant after about the middle of September, although it is still quite small until a few more months have passed. The red scale, on the other hand, may be found in practically all its stages at any season of the year; consequently, the time for fumigating this scale (at least in the nonresistant areas) is less important than for other scales. The purple scale may also be found in various stages at different seasons, although there is a more or less definite hatch in August and September; hence, fumigation to control this scale can best be carried on at that particular season. The eggs of this scale, moreover, are difficult to kill in the colder weather of winter.

The soil in the orchard to be fumigated should be well cultivated, except where nontillage is practiced, in order that the tents may lie in close contact with the ground. Cultivation should not immediately precede fumigation, however. Fumigation should be avoided so far as is possible when cover crops are present or when the ground is furrowed for irrigation. Fumigation too soon after irrigation is likely to result in injury to the trees. It is not desirable that the trees should suffer from lack of water, but fumigation can be carried on with much greater safety when the soil is too dry than when it is too wet.

The cycles of growth of the trees are also related to fumigation injury. The young growth is most susceptible to injury, and the more of it is present the more damage will be done. Of the different cycles of growth, the spring cycle seems somewhat more resistant than the others. Sometimes trees become unusually susceptible in October, particularly in some of the coastal areas, and fumigation may well be suspended for a time within the limits of that month.

Fumigation should not be carried on when the humidity is extremely low, as occurs during periods of dry winds. The desired results in control are likely to be much lessened if there is wind enough to move the tents appreciably. The tree is much more resistant to HCN gas in darkness than in sunlight, especially the strong sunlight of summer. In winter, on the other hand, fumigation may often be carried on satisfactorily a good part of the day, especially if the work is begun in late afternoon or early evening. In general, higher dosages of HCN can be used in winter, since at that season there is less likelihood of tree injury from fumigation.

Bordeaux mixture or any material containing copper, employed either as a spray on the foliage or in the form of a paste applied on the larger branches above the crotch of the tree, should not be followed by fumigation unless in the meantime the winter rains have fallen. The application of bordeaux paste, limited to the trunk only and not extending beyond the crotch, may be followed by fumigation without any particular hazard. Trees have been injured by fumigation five or six months after the application of bordeaux; the bordeaux should, therefore, be applied after rather than before the fumigation, or, for greater safety, the fumigation should be postponed for about a year after the application of the bordeaux treatment. Lemon trees have been injured by fumigation two and one-half to five months after they had been treated with manganese spray (Parker and Southwick, 1941).

### VACUUM FUMIGATION OF CITRUS NURSERY STOCK

Many counties in California enforce restrictions upon the importation. and the movement within their borders, of citrus nursery stock which is a host to scale insects, mites, and other citrus pests. Vacuum fumigation[1] of nursery stock was begun in California probably as early as 1920. Mackie (1922) published the results of vacuum fumigation of nursery stock, dried fruits, grapevines, nuts, and potatoes, using both HCN and $CS_2$. Vacuum fumigation of citrus nursery stock was carried on in 1921 and 1922 at Santa Paula, and such factors as time of exposure, dosage, and tree condition were considered. It proved at this time the practicability of treating citrus nursery stock.

Until about 1940, hydrocyanic acid gas was chiefly used in the vacuum fumigation of nursery stock. Mackie and Carter (1937) found that methyl bromide is fatally toxic to insect life and less likely to cause injury to plant tissues than HCN. Most counties now require a certificate of fumigation with HCN vacuum or methyl bromide before permitting nursery stock to be brought in. Vacuum fumigation requires a dosage of 18 cc. of liquid HCN per 100 cubic feet, a 26-inch vacuum, and a one-hour exposure at not less than 50° F. The nursery stock to be fumigated should not be wet from recent watering, yet neither should it be dry. and before and after fumigation it should not be exposed to direct sunlight.

*Methyl bromide fumigation.*—Nursery stock that is to be fumigated with methyl bromide should be preheated for 2 hours at 80° F., humidity being maintained at a minimum of 75 per cent. Balled stock should be held 10 to 14 days after being dug before fumigation is begun. Methyl bromide is used at the rate of 2½ pounds per 1,000 cubic feet at a temperature of 80° to 85° F. and a relative humidity exceeding 75 per cent. Exposure is for 2 hours. After fumigation, the stock should be kept from direct sunlight.

Ventura County requires all intercounty and intracounty shipments of nursery stock to be vacuum-fumigated with HCN for red scale and other citrus pests. In all other counties, methyl bromide may be substituted for HCN.

[1] For general discussion of vacuum fumigation see Mackie, 1931*b*.

### PETROLEUM OIL SPRAYS

Some of the earliest applications of petroleum oil sprays were on citrus trees, for the control of scale insects, and petroleum oil has been used more and more as the most important spray material for control of various citrus pests. Perhaps more has been learned from the use of oil sprays on citrus than from its use on any other crop. The requirements for control of scale insects on an ever-green citrus tree are more critical than for the same group of insects on a dormant deciduous tree. There is generally a narrower margin between an effective insecticide that is not detrimental to the tree when there is no season in which the tree is actually dormant. Moreover, during the period of dormancy in a deciduous tree, the absence of foliage permits more thorough application of the spray to the twigs and branches, where many serious scale-insect pests thrive.

*Types of oil sprays.*—In the California citrus-growing areas, three general types of oil sprays are in use: emulsions, emulsives, and tank-mix sprays. All three types are "quick-breaking" when applied to the tree. Emulsions and emulsives are most generally employed for citrus spraying, and since these contain different amounts of oil, the amount of dilution with water varies. When an emulsion is used at a dosage of 2 per cent, the practical comparative dosage of oil of the same grade of an emulsive oil is from 1⅔ to 1¾ per cent.

A spray oil emulsion is one that is made by dissolving and (or) suspending a certain amount of one or more emulsifying substances in water and then mixing with petroleum oil by means of violent agitation until a thick and stable mixture is obtained. Depending upon the materials and methods used, the consistency of the emulsion will be "very thick" and hence referred to as "paste" emulsion, or it will be fluid enough to pour out of a 1-inch faucet and is then referred to as "flowable" emulsion. The paste emulsions are little used, now that "flowables" have become so well perfected. The oil content of the oil emulsions now in general use varies from 80 to 90 per cent. Since the oil is already emulsified with water in the stock preparation, violent agitation is not essential for good mixing in the spray tank.

An emulsive spray oil is one in which the emulsifying agent is in solution in the oil. No water is present, and the amount of oil is 98 or 99 per cent of the whole. When an emulsive is added to the water in the spray tank, the emulsion is made by agitation in the tank and by passage of the material through the pump.

Tank-mix spray is one in which the spray oil and the emulsifier and spreader are added separately to the tank of the spray rig and a uniform mixture is obtained by proper agitation in the spray tank (Smith, 1932). The most common emulsifier and spreader is blood albumin.

A miscible oil spray, that is, one in which an emulsifying substance is dissolved in the oil and, when diluted with water, immediately forms a relatively stable emulsion with but little agitation, was formerly much used. It has now been largely replaced by the other types.

The major characteristics of oil sprays for use on citrus are: (1) quality, that is, degree of refinement as expressed in per cent of unsulfonated residue (U.R.); (2) heaviness as expressed by the distillation range and commonly referred to as "grade"; and (3) deposition properties, that is, quantity of oil uniformly deposited on the insect and tree by the spray mixture.

*Quality of the oils.*—The quality or purity of the oil has an important bearing, in California, on tree reaction. Consequently, the lowest unsulfonated residue oil in general use is 92 per cent.

*Grades or heaviness of oils.*—The grades of oil mostly used are classified in five general grades on a basis of distillation range, which is a measure of volatility. Viscosity is also an index to the heaviness of the oil, but viscosity is not thought so valuable an index to the weight of the oil as distillation range. The oils used in citrus spraying in California may be classified as follows (California State Dept. Agric., Bureau of Chemistry, 1945):

| Grade | Distillation at 636° F. | Unsulfonated residue (U.R.) | Viscosity (range accepted) |
|---|---|---|---|
| | *per cent* | *per cent* | *sec.* |
| Light | 64–79 | 90 | 51–62 |
| Light-medium | 51–61 | 92 | 55–70 |
| Medium | 40–49 | 92 | 70–79 |
| Heavy-medium | 28–37 | 92 | 77–83 |
| Heavy | 10–25 | 94 | 83–97 |

*Depositing properties of oils.*—The amount of oil deposited on the tree and the uniformity of the deposit are principally determined by the stability of the diluted oil emulsion and the efficiency of the wetting and spreading agent in preventing "beading" of the spray mixture.

*What oil to use.*—Under present conditions there is apparently little basis for a choice between an emulsive or a flowable emulsion, or among the proprietary brands of major companies. The most important consideration is choice of the proper grade of oil to use. The choice is determined by the following factors: (1) the particular locality in the citrus area; (2) the variety of citrus tree; (3) the insect or mite, or the complement of pests present; and (4) the season of the year.

Under the discussions of the various pests, earlier in this chapter, the grade of oil, dosage, and time of application were given. The following discussion explains why such recommendations were made, and offers other information necessary for the intelligent use of such sprays.

The difference in localities as influencing the oil to use may be considered as it relates, respectively, to coastal, intermediate, and interior conditions. The citrus tree is likely to respond most unfavorably to oil sprays in the interior and least unfavorably in the coastal area. Consequently, oil of light-medium grade is as heavy as should generally be used on orange trees in the interior, and even this grade is objected to by some growers and packing-house managers. On lemons, a medium oil is the heaviest that should be used in the interior; a heavy-medium, or in some restricted areas a heavy oil, may

be used in the coastal area. In the intermediate areas a medium oil may be used on oranges, and in some parts of the same area a heavy-medium oil on lemons.

The difference between the orange and lemon tree in their reaction to oil sprays was indicated in connection with the difference in locality. The kind or species of insect to be controlled is equally important. The scale insects classed as unarmored, such as the black and citricola scales, are controlled with lighter grades of oil than are the armored scale insects, such as the red, yellow, and purple scales. A light-medium oil is satisfactory for use against the black and citricola scales. Where the citricola scale alone occurs, even the light grade of oil may be satisfactory. For the red, yellow, and purple scales, oil of medium grade is as light as will give control when infestations are moderate to heavy; on lemons, where conditions will permit, a heavy-medium or heavy oil is more satisfactory. There is now in limited use a program of two annual treatments with a light-medium oil for the control of red scale on lemons (Newcomb, 1947).

The last of the factors that govern general spraying is the season of the year. The summer or early fall months—more specifically, mid-July to the end of September—are preferable for the application of oil sprays to orange trees. The season for spraying is usually determined by the susceptibility or "condition" of the black and purple scales, and by the time when the effects on the tree and fruits are likely to be least adverse. For lemons the best season for spraying is later in the fall than for oranges, that is, October and November. At this time there is less likelihood that a "hot spell," inducing a drop of lemon fruits, will occur soon after the oil is applied. April and May also constitute a good season for the use of oil on lemons, although treatment in the interior localities should be given in April only.

Oil sprays applied for the control of scale insects will at the same time control the citrus red mite and the citrus bud mite. The heavier the oil the longer the period of control for the red mite. On the citrus bud mite, light-medium oil is as effective as any of the heavier grades. In some localities, oil spray is necessary primarily for the citrus red mite or the citrus bud mite rather than for the associated scale insects.

*Toxicants added to oil.*—Much research has been done in an effort to find a suitable toxicant to add to petroleum oil with the objective of making a more effective spray with a lighter grade of oil and hence minimizing adverse tree reaction. Rotenone has been incorporated with the lighter grades of oil —light-medium, light, and even with kerosene—and has been used for more than a decade. "Rotenized oils" are very effective for black scale control, particularly in the cooler coastal localities, but they are not so consistently effective in control of red scale also as to justify general recommendation of their use. Rotenized oils are highly effective in control of citrus aphids.

The use of DDT in combination with various grades of oils has been extensively studied. Against unarmored scales such as citricola and the black scales, a kerosene-DDT spray is highly effective, since the scales hit by the spray mixture are killed (Ewart, 1946, and Ewart and DeBach, 1948).

Against red and purple scales, which are armored scales, a kerosene or other very light fraction of oil in which DDT is dissolved affords promising results (Lindgren, LaDue, and Harris, 1946; Ebeling, 1945 and 1947; Carman, 1948). The effectiveness of the treatment against these scales is attributable to the residue of DDT on the tree, which prevents the settling and development of the newly hatched crawlers, since the material does not kill many of the larger scales that are present at the time of treatment. Until more information is available concerning the effect of DDT on the biological-control aspects of citrus pest control, the general use of DDT cannot be recommended.

*Injury from oil sprays.*—"Acute" injury, that is, leaf and fruit burn and drop, may be expected if high temperatures (100° F. or higher) occur within several days after the application of an oil spray. Fruit and leaf drop can be expected if the trees are in need of irrigation at the time the oil sprays are applied. However, acute injury, reflected by leaf or fruit drop, or both, sometimes occurs without relation to the adverse conditions mentioned above. Preliminary investigations by Stewart and Ebeling (1946), which are being continued and expanded by Stewart and Riehl,[1] indicate that certain esters and salts of 2,4-dichlorophenoxyacetic acid (2,4-D) incorporated in the conventional oil sprays at a dosage of 4 to 8 parts per million, on the basis of the total spray mixture, may be useful in mitigating these and possibly other aspects of injury from the oil. Further extensive studies with these materials are necessary, however, before the possible general utility of plant-growth-regulating substances as amendments to oil sprays on citrus can be fully determined.

Some aspects of "chronic" injury from the use of oil sprays are: dead wood among the inner parts of the tree; impairment of the color of oranges and lemons; reduced crop in some seasons, particularly of fruits on the north side of the tree; increase in the amount and severity of granulation of Valencia oranges and reduction in the soluble constituents of the orange juice (Bartholomew and Sinclair, 1944).

Oil spray applied on navel oranges in parts of the San Gabriel Valley accentuates the incidence of water spot (Ebeling and Klotz, 1936).

*Compatibility of oil sprays with other materials.*—Injury may be expected if oil spray is applied over DN-Dust within approximately two weeks after application and over sulfur within approximately two months after application. Neither of these materials should be used in combination with oil. The principal adverse effect on citrus of the addition of other commonly used materials, such as cryolite and zinc, is that the stability, and hence the depositing properties of the oil emulsion, may be seriously affected. The added materials may react with the emulsifier or otherwise interfere with emulsification in such a way as to cause the emulsion to deposit too much oil on the plant and hence produce injury, or the emulsion may become so stable that it does not deposit enough oil on the plant to kill the insects. Since proprietary oil emulsions and emulsives are almost exclusively used, the addition of other materials to these oil sprays should be only in accordance with the manufacturer's rec-

[1] W. S. Stewart and L. A. Riehl, unpublished data, 1947.

ommendations. This is essential because various manufacturers use different emulsifiers and other accessory materials in the preparation of their products and a given material such as zinc oxide may seriously affect one particular product and yet have little or no effect on another. In general it may be said that emulsions are more compatible with other materials, particularly solids, than emulsives.

## Other Insecticides

### NICOTINE

Nicotine has long been the standard material for control of citrus aphids. Within the past few years it has also been used for control of citrus thrips. Nicotine sulfate is the form used in sprays for control of aphids. Formerly it was used solely in combination with hydrated lime for making nicotine dusts. However, there has been an increasing use of the alkaloid or free nicotine in the preparation of dusts for control of aphids, mainly because of the superior physical properties of these dust mixtures. (See p. 738 for commonly used formulas for aphid control.)

For control of citrus thrips either nicotine sulfate or the "fixed nicotine" preparation Black Leaf 155 is used in combination with sugar. Alkaloid nicotine is not suitable for this use. The application is made either with a spray-duster or with broom guns. (See p. 691 for details.) Zinc sulphate for correction of zinc deficiency should not be used in combination with nicotine, although zinc oxide is widely used in this way.

### ROTENONE

Rotenone is used in several ways: in finely divided powdered root added to oil sprays, usually after the oil is put into the spray tank; as resins or extractives of rotenone-bearing roots, or as technical grade rotenone in solution in petroleum oil; and also as a concentrated extract of rotenone-bearing roots without petroleum oil. The principal use for rotenone is in combination with oil for control of unarmored scale insects and aphids. (See pp. 720 and 738 for details.) Rotenone in dust mixtures has no general use in citrus pest control.

### PYRETHRUM

Pyrethrum extract containing approximately 2.0 per cent pyrethrins is used for control of greenhouse thrips, either in combination with petroleum oil or without it. (See p. 695 for details.)

### DINITRO-*o*-CYCLOHEXYLPHENOL
### (DN or DNOCHP)

Dust preparations containing DN or the dicyclohexylamine salt of this compound have been used for about a decade in control of citrus red mite. The material is also effective in control of the six-spotted mite, but it has practically no value in the control of the citrus bud mite or the citrus rust mite. A wettable preparation of DN known as DN-111 is used as a spray in some areas for control of the citrus red mite and the six-spotted mite. Cryolite for control of orange worms is commonly combined in dust

and spray mixtures with DN. Zinc oxide is also combined with DN-111 in sprays. Injury to foliage and fruit is likely to occur if the temperatures exceed about 92° F. within a few days after the application of DN materials on citrus trees. (See p. 683 for details.)

### BIS-(*p*-CHLOROPHENOXY)-METHANE (K-1875)

As the result of extensive investigations, bis-(*p*-chlorophenoxy)-methane, or K-1875, came into commercial use early in 1948 for control of the citrus red mite. Preliminary results from the use of this material in control of the six-spotted mite have been satisfactory, except when the application is made with the spray duster. However, results in control of the citrus bud mite, the citrus rust mite, or any of the other pests of citrus, have not been promising. Present indications are that the material is relatively nontoxic to beneficial insects.

A wettable powder containing 40 per cent of this compound is being marketed under the trade name "Neotran." It is applied in water suspension with either the spray duster or the conventional spray rig. Dust formulations of K-1875 have not been consistently effective in control of the citrus red mite, although they are promising enough to justify further study.

K-1875 appears to be compatible with the more important insecticides, fungicides, and mineral-element-deficiency materials commonly used on citrus. Because of its low order of toxicity to warm-blooded animals, it does not present a hazard to the men who apply it, nor are residues on the fruit considered to be of significance. (For full discussion of this material see Jeppson, 1948.)

### TARTAR EMETIC

Tartar emetic was formerly used generally for control of citrus thrips. However, it is now used only on a relatively small proportion of the acreage because there has developed a race of citrus thrips that is resistant to the tartar emetic treatment. Tartar emetic must be combined with sugar in order to be effective against citrus thrips. It has been most generally applied with a spray duster. There has been limited use of a mixture of tartar emetic and sugar for control of snails. Materials other than sugar should not be used with tartar emetic. (See pp. 690–691 for details.)

### DICHLORODIPHENYL TRICHLOROETHANE

DDT, or, more specifically 1,1,1-trichloro-2,2-bis (*p*-chlorophenyl)-ethane, shows promise in control of citricola, black, soft (or: soft brown), red, and purple scales, citrus thrips, and greenhouse thrips. It is at present being used for the control of citricola scale and citrus thrips in Tulare County, California, and for control of citrus thrips on lemons in several areas in southern California. Against the citricola scale it is used in solution in kerosene or other especially light-grade oils, in late winter. At the time these scales begin hatching in early May, which is also an appropriate time for controlling citrus thrips, a dust mixture containing 2 per cent DDT and 85 per cent

sulfur is useful against both insects. Against citrus thrips alone it is principally used as a wettable powder applied with the spray duster, although DDT–sulfur dust is also used for this purpose in Tulare County, California. As yet, there is no commercial use of DDT on citrus for other purposes.

It was clearly evident during the 1946 and 1947 seasons that DDT might seriously upset the vedalia–cottony cushion scale complex. Therefore, the general use of DDT on citrus cannot be recommended as yet. (See pp. 691–692 for details.)

The methoxy analogue of DDT known as methoxychlor or DMDT has not as yet shown promise for use on citrus.

### OTHER CHLORINATED HYDROCARBONS

DDD (dichlorodiphenyl dichloroethane), benzene hexachloride, chlordan, and chlorinated camphene ("Toxaphene") have not as yet shown promise for use on citrus in California.

### HEXAETHYL TETRAPHOSPHATE AND TETRAETHYL PYROPHOSPHATE (HETP and TEP)

Hexaethyl tetraphosphate (HETP) was first used in a limited way commercially during the spring season of 1947 for control of aphids on citrus trees. It was generally applied as a liquid, by means of a spray duster, or as a dust. Subsequent investigations strongly indicate that the principal toxic material in HETP is tetraethyl pyrophosphate (TEP). Consequently, the present trend is toward the use of TEP for those purposes for which HETP was formerly used. Until experimental work now in progress with standardized TEP preparations is completed, it will not be possible to indicate accurately the dosage and formulation requirements for use in control of aphids on citrus.

Although TEP is known to be toxic to certain other pests on citrus, present indications are not promising for its use in practical control of any species other than aphids.

These organic phosphate materials should be handled very carefully by operators, in order to avoid possible adverse effects.

### PARATHION
(*o,o*-diethyl *o-p*-nitrophenyl thiophosphate)

Parathion first became available early in 1947. Laboratory and field studies with it during that year afforded promising results against many of the citrus pests. The material was used, in the main, as a spray employing a wettable powder containing 25 per cent parathion and applied both with the conventional spray rig and with the spray duster. However, dust formulations containing 1, 2, and 4 per cent parathion were also used. An extensive program of field study with parathion is currently (1948) in progress in an effort to determine optimum dosages and most effective formulations and means of application in control of those pests against which it appears promising.

In common with the other organic phosphate materials, HETP and TEP,

mentioned above, parathion should be handled very carefully by operators, in order to avoid possible adverse effects.

### THIOCYANATES (Lethanes)

The proprietary thiocyanate preparations, that is, lethanes, are but little used on citrus for control of citrus aphids and greenhouse thrips. Against aphids, the material is used in both spray and dust preparations. Against the greenhouse thrips, it is used in combination with low dosages of petroleum oil.

### SULFUR

Sulfur is used as a dust, and as wettable sulfur in combination with lime sulfur, for control of citrus thrips and citricola scale in Tulare County, California. Recently, DDT (2 per cent) has been incorporated with sulfur dust for control of these insects. Sulfur dust, and wettable sulfur, alone, or in combination with lime sulfur, are also used in sprays for control of the citrus rust mite. The sulfur–lime sulfur sprays are also effective for winter and early spring season use in control of the citrus bud mite. Lime sulfur alone, or sometimes in combination with miscible oil, has been commonly used in late winter for control of the citricola scale in central California. The general specifications for sulfur used for dusting and in wettable sulfur for spraying are: fineness, 95 per cent through 325-mesh screen, and sulfur content of at least 95 per cent.

Sulfur is likely to cause injury, as is evidenced by burning of fruits particularly, when temperatures are high, that is, 90° F. or above. Its use on citrus is therefore limited.

### CRYOLITE

Cryolite from both natural and synthetic sources is widely used for control of orange worms. It is applied as a dust alone or in combination with DN, or as a spray alone or in combination with nicotine, rotenone, zinc oxide, or petroleum oil. Cryolite is also used for control of Fuller's rose weevil and Diabrotica beetles whenever measures against these insects are necessary.

## APPLICATION OF INSECTICIDES

The application of insecticides on citrus trees is done chiefly by pest-control companies, on a contractual basis, and by coöperative pest-control organizations. However, many orchardists with extensive plantings have their own equipment for applying insecticides.

### FUMIGATION

The application of HCN is a highly specialized operation and for that reason has been treated under the general subject of "Fumigation," p. 771.

### SPRAYING

*Regular spray rigs.*—Spraying is done with conventional mobile spray equipment. In recent years, spray pumps and tanks of increased capacity

Fig. 252. Typical spray equipment applying oil spray on orange trees. Note tower man spraying tops of trees from "catwalk." (Photo by R. S. Woglum.)

have been used, as a step toward more efficient operation. The spray pumps generally have a capacity of 35 to 85 gallons per minute. The tanks are usually of 500-gallon size, although many are larger. Towers for adequate coverage of the tops of the trees are necessary and standard equipment. The type at present in general use is the hydraulically operated telescoping mast, capable of elevating the spray men to a height of about thirty feet above the ground. A platform, or "catwalk," at the top of the mast makes it possible for a spray man to spray almost directly downward on the citrus tree (fig.

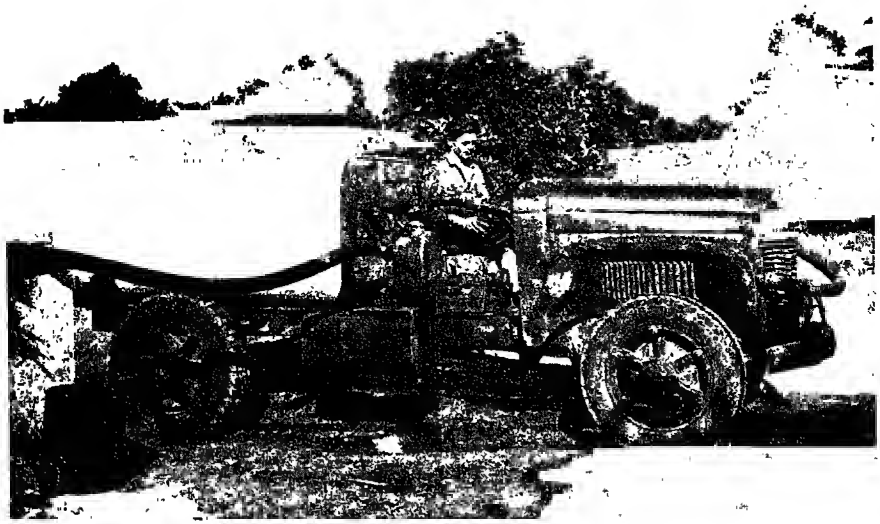

Fig. 253. Service or "nurse rig" for servicing spray rig in the orchard. (Photo by R. S. Woglum.)

252). In practice, one or two men spray from the tower (two when very large trees are being treated), and two from the ground. The operating pressure at the pump is at least 600 pounds. The opening in the disk of the spray gun varies from 7/64 to 9/64 inch. From 25 to 35 gallons of spray mixture are applied on an average-sized orange tree for the control (for example) of red scale. The spraying technique is such that thorough coverage of the tree is obtained, with particular emphasis on the inner part of the tree, where complete coverage is so essential to satisfactory results in control of scale insects.

The development of service rigs, commonly called "nurse rigs," has greatly expedited the spraying operation. These mobile tanks, with pumps having a capacity of 100 to 300 gallons per minute, service the spray rig in the orchard, delivering either (1) a mixed spray or (2) the water and other ingredients singly, which are mixed as the spray rig is being filled (fig. 253). (For a full account see Woglum, 1947*b*, and Woglum and Lewis, 1947*b*.)

*Broom guns.*—Broom guns, which have banks of nozzles in rows of 3 to 8, are commonly used in the application of material for control of citrus thrips and citrus aphids or for the application of elemental nutritional sprays. The gallonage per tree may vary from 2 gallons to 12 gallons, depending upon the purpose of the treatment and the material used. When making broom-gun applications the spray men usually ride on the spray rig (fig. 254).

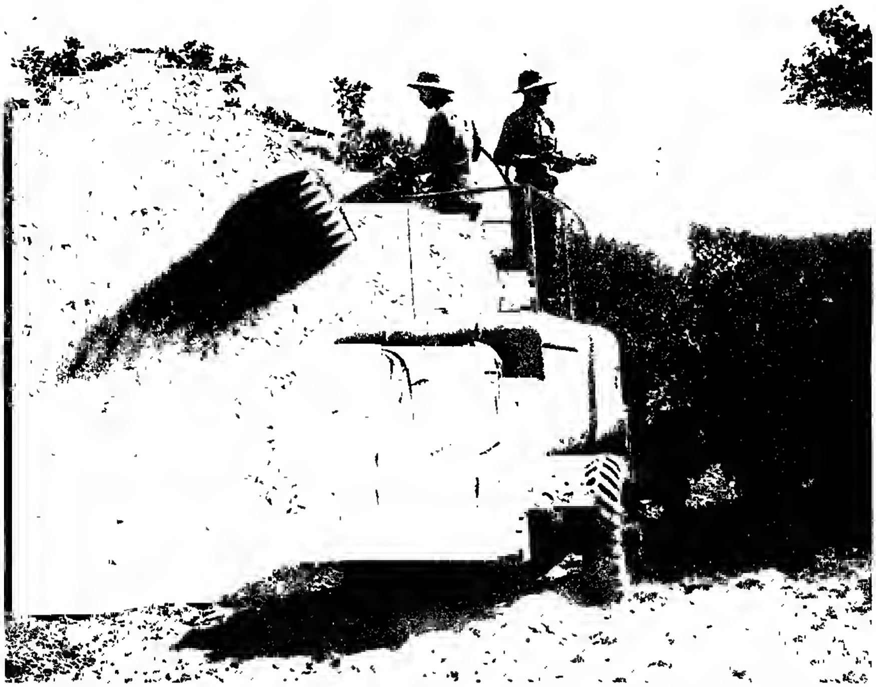

Fig. 254. Spraying with broom guns to apply tartar-emetic-and-sugar spray on orange trees.

*Boom sprayers.*—In recent years the mechanized application of sprays has been widely developed. "Booms" of many types and designs have been constructed, for the most part by pest-control operators, and are becoming greatly improved. Although the best application by boom sprayers cannot be considered as good coverage as that obtained by the usual hand-operated spray guns, especially for the inner part of the tree, application with the more recently constructed booms is almost as good as hand application. Essentially, the boom is an upright extension, usually mounted on the rear of the spray rig, on which are mounted varying numbers of spray guns or nozzles which mechanically move back and forth, or up and down, or with a circular motion (figs. 255, 256). The number of nozzles varies from 6 to 32, depending upon the pump capacity and the design of the boom. The pumps on boom

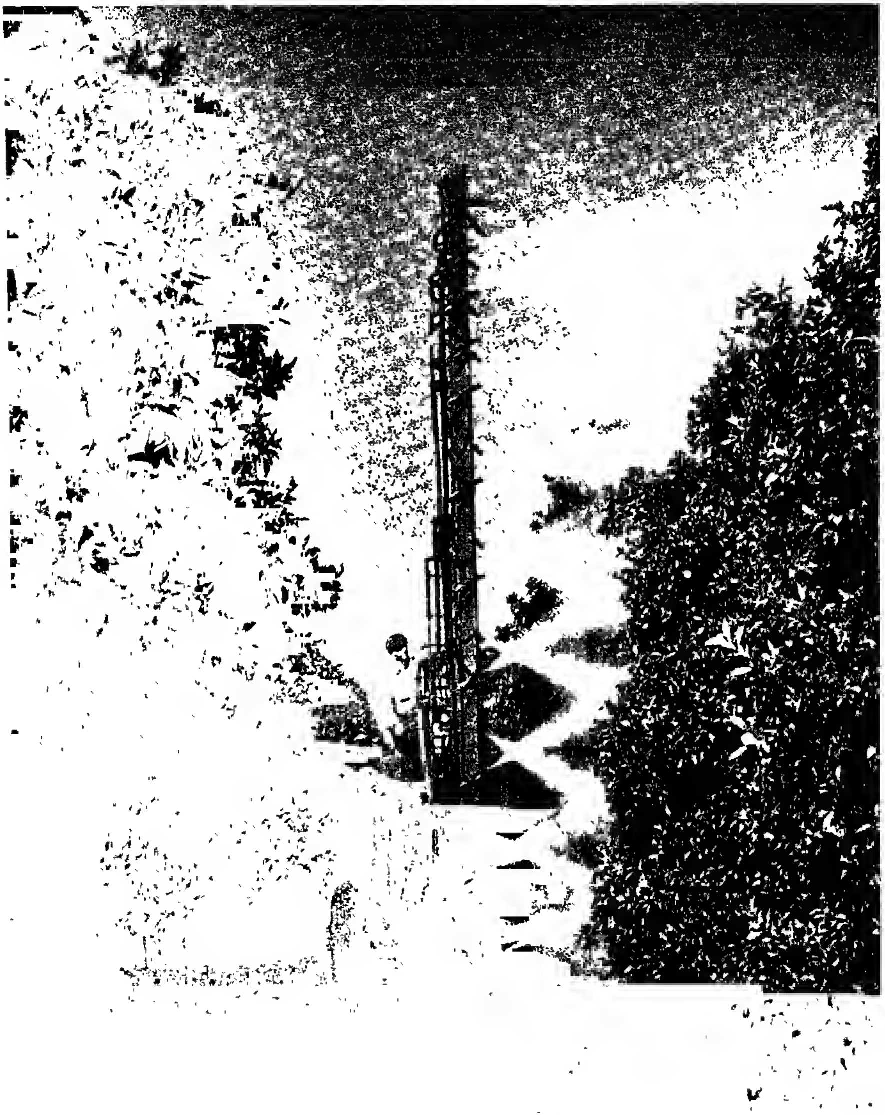

Fig. 255. The Loucks boom sprayer. The boom is 22 feet high and is equipped with 22 "short" guns which are installed in two separate series. There is also an independent 12-foot boom equipped with mist-type nozzles for close-up work. (Photo courtesy Hardie Mfg. Co.)

rigs vary in capacity from 55 to 140 gallons per minute. (For full discussion of booms with illustrations see Woglum, 1944*a*, 1945*a*, 1946*b*, 1946*c*.)

*"Speed sprayer."*—The "speed sprayer," which is widely used in Florida on citrus, and elsewhere on deciduous trees, has not yet been generally adopted in California for use on citrus. This machine employs a very large volume of air to distribute the spray mixture on the tree (fig. 257). Investigations with

Fig. 256. The Corona Foothill Lemon Company boom sprayer. This is a double boom 15 feet in height which may be adjusted to spray on each side for "skeleton" coverage, or all guns may be directed to one side for more thorough coverage. (Photo by R. S. Woglum.)

an improved model of this equipment are now in progress. Its principal advantages are mechanical simplicity and rapid application with a minimum man-power requirement.

DUSTING

Equipment for applying dusts has been greatly improved in the past decade. In connection with the development of DN-Dust for the control of mites on citrus it was necessary to improve the existing methods of application (Boyce and Kagy, 1941). A result is the present dusting equipment, which employs the principle of using a large volume of air (20,000 to 30,000 cubic feet per minute) at a relatively low velocity (approximately 75 miles per hour). The air-borne dust is discharged through large vertical fishtail orifices (fig. 258) in such a way that the entire tree is covered by a vertical band of dust as the equipment is moved past it. "Flippers" terminating each

discharge orifice of the fishtails mechanically oscillate forward and backward, with a consequent movement of the fruit and foliage which permits more thorough application of the dust mixture throughout the inner parts of the tree and on the "back sides" of leaves and fruits. The mobile dusting equipment travels between each two rows of trees and discharges dust to both right and left (fig. 259); hence all trees are dusted from both sides. Dusting should only be done when the air is quiet, and therefore is done

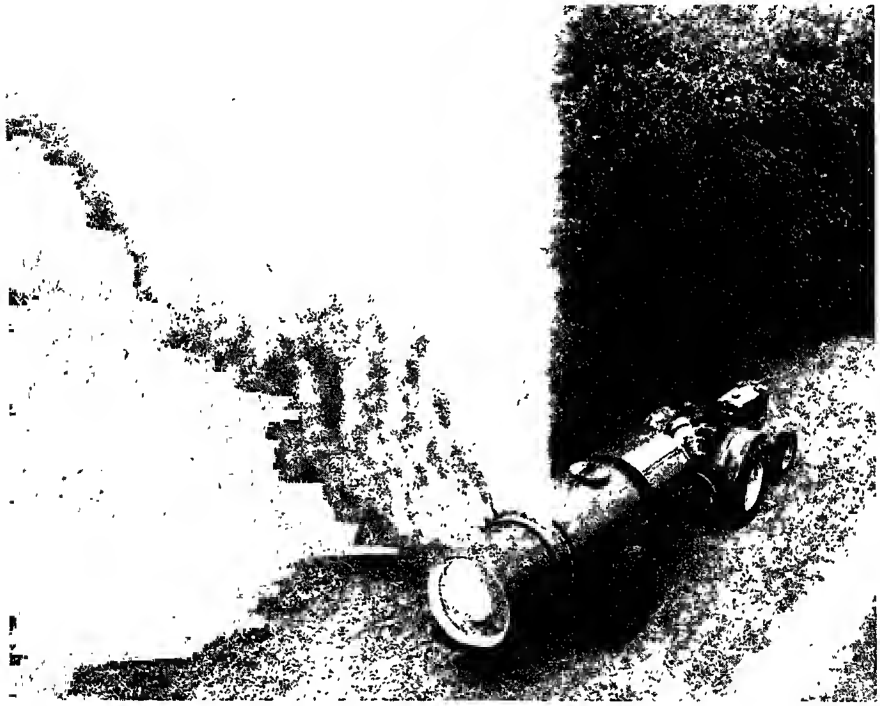

Fig. 257. Speed sprayer in operation on citrus. (Photo courtesy of Food Machinery Corp.)

almost exclusively at night. In the application of dust mixtures such as DN-Dust and cryolite the travel rate of the dusting equipment should not exceed three miles per hour. (For details relative to technique of citrus dusting see Sloop, 1946.)

SPRAY DUSTING

The local term "spray dusting" indicates the application of finely divided spray mixtures conveyed to the tree in an air blast (fig. 260). Many of the conventional citrus dusters are equipped with pump and tank and with nozzles in the fishtail discharges for the application of liquids. As small an amount as 20 gallons per acre uniformly distributed on the outer surfaces of the trees can be applied with this equipment. The smaller amounts of spray mixture are generally used for the control of citrus thrips. Larger quantities,

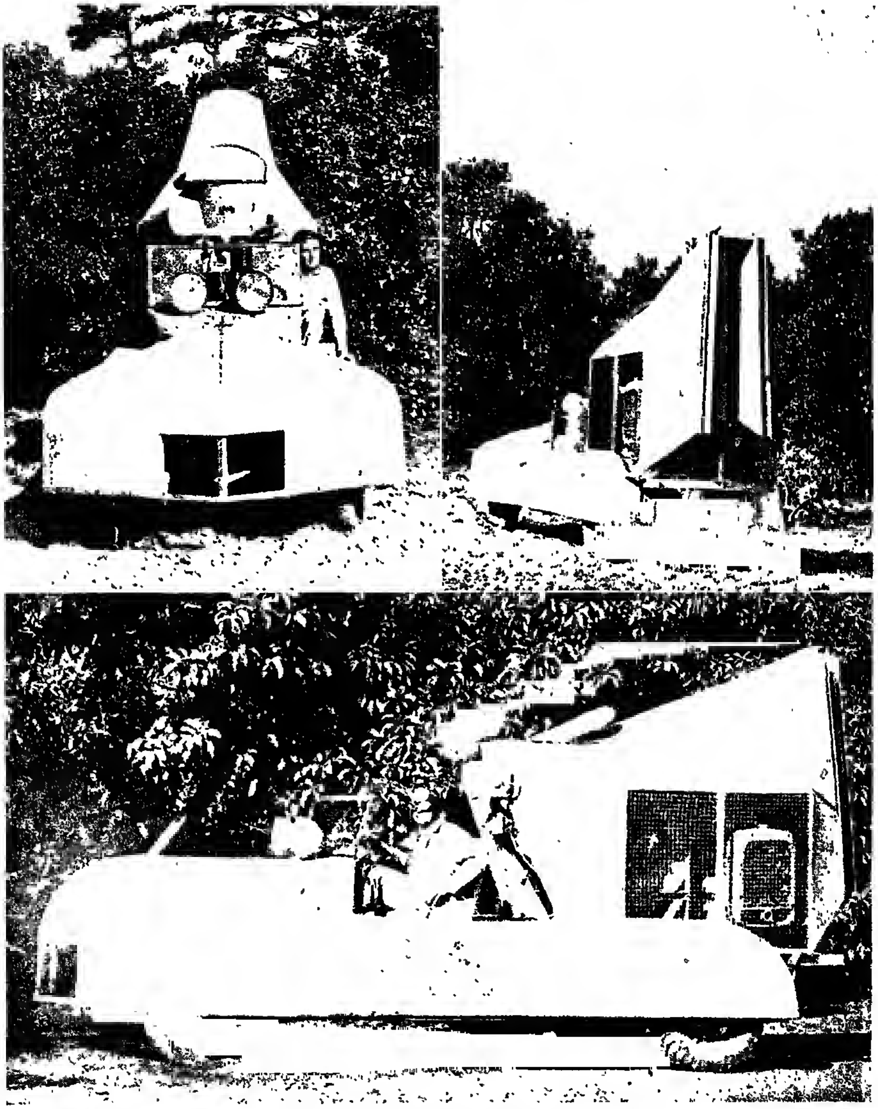

Fig. 258. Citrus duster. Note streamlining of duster and truck to avoid tree and fruit damage in operation in "tight" orchards. (Graves and Howley equipment; photo by R. S. Woglum.)

however, to as much as 500 gallons per acre, are applied for control of aphids and red spiders or for the application of nutritional sprays containing zinc or manganese.

An additional feature of this equipment is that small quantities of liquid

may be applied simultaneously with dust mixtures for adhesive and other purposes.

APPLICATION BY AIRCRAFT

The application of insecticides on citrus by means of aircraft (fig. 261) has not as yet been generally effective enough to compete with application from the ground. However, improvements in aircraft equipment and the techniques of applying dust and sprays, including application by helicopter,

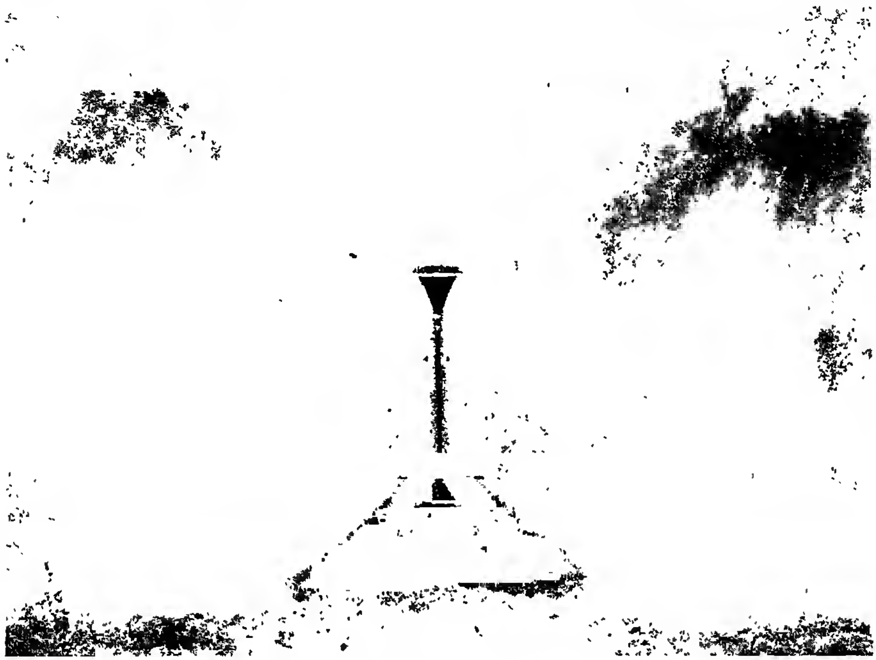

Fig. 259. Rear view of citrus duster in operation.

together with the array of new and promising insecticides, may result ultimately in satisfactory control of certain insects by application of materials from aircraft.

AEROSOLS

Heat-generated aerosols, or insecticide "fogs," and gas-propelled aerosols, also, are now being studied. There has been a very limited commercial use of thermal aerosol machines for the application of HETP and TEP for aphid control on citrus.

CITRUS PEST CONTROL IN ARIZONA

Pest-control problems on citrus in Arizona are relatively minor in comparison with those in California and Florida. The citrus thrips is the only generally important pest of citrus in Arizona and the tartar emetic–sugar treatment is applied with the spray duster or with broom guns. However,

there are indications that the citrus thrips is becoming resistant to tartar emetic in several localities (Woglum, 1947*a*; Roney and Lewis, 1948), and DDT is being used as a substitute. There has been limited application of DDT with thermal aerosol machines, and with aircraft, for control of citrus thrips.

Grasshoppers may be destructive in localized areas unless controlled with sodium fluosilicate bran sawdust bait or with sprays or dusts containing chlordan or other toxicants applied directly to the citrus trees.

### CITRUS PEST CONTROL IN TEXAS

Until about 1937, scale insects, the California red scale in particular, were very damaging to Texas citrus orchards, often requiring fumigation or spraying with oil annually. Friend (1946) writes: "During the past 10 years, however, natural control has taken care of this destructive insect (California red scale). 'Friendly' fungi and several types of insect parasites and predators have made it unnecessary for most Valley growers to use any kind of artificial control for any type of scale insect or white fly that infests citrus trees in this area."

Fig. 260. Spray duster in operation. (James West equipment; photo by Frashers Fotos.)

In the relatively few places in Texas where measures must be taken for the control of scale insects injurious to citrus, oil spray is usually applied with conventional spray equipment. In the Winter Haven locality "speed sprayers" are also used.

The principal material regularly used on citrus in Texas is sulfur for con-

trol of the citrus rust mite and the Texas citrus mite. Sulfur dust is applied by both ground and aircraft equipment.

## CITRUS PEST CONTROL IN FLORIDA

From 1933 to 1939, changes in spray practices for pest control in Florida were necessitated by new and important developments in cultural practices in the citrus orchards, particularly in the application of copper, zinc, and manganese in sprays for nutritional purposes. It should be noted that copper had already been in general use for many years as a fungicide; hence it serves

Fig. 261. Aircraft application of dust on citrus. (Photo by C. F. Gallagan.)

a dual purpose (Thompson, 1939). Since the late 1930's, the spray program has been related closely to a carefully planned and coördinated program of insect and disease control, together with maintenance of adequate nutritional levels of copper, zinc, magnesium, and manganese in the trees, with the objective of preventing an acute need for correction of any of the problems. In furtherance of that objective, the Advisory Committee of the Florida Citrus Commission each year prepares and issues a *Better Fruit Program Spray and Dust Schedule* for that particular year. It is a comprehensive schedule based on information supplied by state, federal, and industrial organizations, and includes four separate schedules the titles of which are:

SCHEDULE A. For grapefruit, Temple oranges, and Satsuma oranges in areas where scab and melanose are expected to be severe and for scales, whiteflies, rust mites, six-spotted mites, and purple mites.

SCHEDULE B. For oranges and tangerines throughout the state and grapefruit in areas where scab is of minor importance and melanose is expected to be severe, and for scales, whiteflies, rust mites, six-spotted mites, and purple mites,

SCHEDULE C. For the control of scales, whiteflies, rust mites, six-spotted mites, and purple mites, when neither scab nor melanose is important.

SCHEDULE D. Use for mites only.

In addition to these four schedules there are two sections entitled "General Instructions" and "Special Recommendations."

In order to indicate the pest-control requirements and the general complexity of citrus pest control in Florida, Schedule B and the section entitled "Special Recommendations" of the "Spray and Dust Schedule for 1948 Season" will be given below. Since it is not feasible to reproduce here the entire schedule for Florida, it should be understood that intelligent use of Schedule B requires reference to other parts of the Spray and Dust Schedule.

## BETTER FRUIT PROGRAM*

### SPRAY AND DUST SCHEDULE FOR 1948 SEASON

#### SCHEDULE B

*(All weights and measures are calculated per hundred gallons of water.)*

For oranges and tangerines throughout the state and grapefruit in areas where scab is of minor importance and melanose is expected to be severe, and for scales, whiteflies, rust mites, six-spotted mites, and purple mites.

I. Dormant spray, January. This application is extremely effective in controlling rust mites and for nutritional purposes before bloom. Use 5 lbs. wettable sulfur plus either 2 to 2½ gals. of liquid lime-sulfur or 4 to 8 lbs. dry lime-sulfur; and add 3 lbs. zinc sulfate for nutritional purposes.

ALTERNATE. If purple mites are present use 3 lbs. zinc sulfate, 1 lb. hydrated lime, 10 lbs. wettable sulfur, and ⅔ lb. DN,† adding DN when tank is ¾ full, or DN-sulfur dust.

II. For melanose apply 1 to 3 weeks after fruit has set. Use copper spray† plus 5 to 10 lbs. wettable sulfur; if zinc was omitted in I, add 3 lbs. zinc sulfate and 1½ lbs. hydrated lime.

ALTERNATE. If purple mites and/or six-spotted mites are numerous, use neutral copper‡ plus 5 to 10 lbs. wettable sulfur and ⅔ lb. DN. Do not use DN on tender foliage or when temperature is above 88° F.

ALTERNATE. For purple mites and/or six-spotted mites and to reduce excessive scale population in the spring, use copper spray with oil at 1.3 per cent and omit zinc, lime, and sulfur. See note under scale control in special recommendations as to copper oil.

III. If rust mites become numerous before the oil spray IV, use 5 to 10 lbs. wettable sulfur plus either 1½ gals. liquid lime-sulfur or 3 to 6 lbs. dry lime-sulfur; or dust with sulfur. This application is seldom necessary and should only be used if inspection shows rust mite infestation.

IV. For scale insects and whiteflies, June through July, but June 15 to July 15 preferred. Use oil at 1.3 to 1.5 per cent.§ This spray should not follow closer than

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* From the Florida Citrus Commission, Lakeland, Florida.

† All copper sprays are based on 3-3-100 bordeaux or its fungicidal equivalent in other forms of copper which have proved satisfactory.

‡ DN is the common term for dinitro-o-cyclohexyl phenol.

§ All percentages of oil in oil sprays are percentages of actual oil, not percentages of emulsion or stock.

3 to 4 weeks after applications II or III. This application and its thoroughness are extremely important. See special recommendations on scale control. August and September oil spraying reduces solids in the juice and delays coloring.

V. For rust mites, starting about August 15. Use, as needed, on early and mid-season oranges and tangerines, 10 lbs. wettable sulfur; or dust with sulfur; and on late oranges and grapefruit 1 gal. liquid lime-sulfur or 3 to 4 lbs. dry lime-sulfur may be added to the above sprays.

ALTERNATE. For scales and purple mites, in October, use oil at 1.3 to 1.5 per cent.

VI. For purple mites, six-spotted mites, and rust mites, late October through December, use 10 lbs. wettable sulfur plus ⅔ lb. DN; or DN–sulfur dust. Examine summer and fall growth for purple mite infestations.

ALTERNATE. For rust mites only, use 5 to 10 lbs. wettable sulfur plus 2 gals. liquid lime-sulfur or 4 to 8 lbs. dry lime-sulfur; or dust with sulfur. Rust mites are difficult to see on colored fruit; consequently, leaves should be examined.

## SPECIAL RECOMMENDATIONS

*Scale control:* In spraying for scales particular attention should be given to covering inside twigs and wood as well as the undersurfaces of the leaves because the oil must come in contact with the scales to kill them.

Red scales are extremely difficult to control and if present even in small numbers are potentially dangerous. July 1 to August 1 is the preferred period for red scale control, but for varieties to be moved early in the fall oil spraying after July 15 may reduce solids and retard coloring. In groves having a heavy carry-over of scale in the spring a combination of oil emulsion and copper may be used in place of the regular melanose spray. Fruit marking may occur and frequently is serious. However, there is less injury when the spray is applied before the fruit reaches ¾ inch in diameter. Growers should keep this in mind and realize that there is some risk in using copper oil at any time after the fruit is set. Grapefruit are less susceptible to this injury than oranges. Not all coppers and oils are compatible, and in some combinations the copper is flocculated and lack of melanose control may result or considerable fruit burn may occur. When using a proprietary copper with oil, consult your supplier for information on the compatibility of the particular copper and oil emulsion used and examine the spray mixture in a glass container before using to see whether it has a fine texture or whether the copper is flocculated (curdled) into small flakes or lumps giving the spray mixture a coarse-textured appearance. If flocculation occurs, use a deflocculator recommended by the manufacturer of the oil used. The copper is usually used at the regular rate and oil at 1.3 per cent actual oil. A copper oil spray does not eliminate the necessity for the regular summer oil application.

*Mealybugs:* During May and early June, mealybug infestations may be reduced if an oil emulsion is applied in such a way as to wash off as many mealybugs as possible.

*Rust mites:* Winter damage caused by mites may be severe to both trees and mature fruit. This emphasizes the importance of application VI on all schedules. Periodic inspections for mites should be made during the entire period that the crop is on the trees, including the rainy season. Rust mites are not controlled by rain.

*Red spiders:* This is a group name and includes both six-spotted mites and purple mites. The six-spotted mites are practically always found on the underside of the leaves and cause a yellow spotting and sometimes a distortion of the leaves; in cases

of severe infestations a heavy droppage of leaves may occur. Purple mites are most common on oranges and tangerines and work on the green twigs and both sides of the leaves. During periods of dry weather heavy infestations may cause leaf drop and twig injury, and in the fall dying of the twigs commonly occurs. During October and November inspect the twigs as well as the leaves for infestations on summer and fall growth.

*Aphids:* Aphis control is particularly important on young trees, older trees that are slow in growing and sparse of foliage, or where infestation is very heavy during blooming period. If control measures are necessary, they should be carried out while infestation is light and foliage young. After a large percentage of leaves are curled or new growth nearly mature (4 to 5 inches long), control is not practicable. Coverage is very important. Schedule: January and February—spot spraying or dusting for small colonies. March and April—spray or dust before many leaves are curled. Use either 3 per cent nicotine–lime dust, applied during calm weather, or add nicotine sulfate to any spray listed in the schedule at the rate of 1 lb. per 100 gals. of the diluted spray. Hexaethyl tetraphosphate (HETP) at 1-1600 of the active ingredient per 100 gallons is an effective aphicide. Benzene hexachloride (3 lbs. 6 per cent gamma isomer per 100 gals.) is also effective in killing aphids, but should not be used between the time the fruit has set and September 1st. Neither HETP nor BHC should be used in sprays containing lime.

*Plant bugs:* Plant bugs cause considerable fruit damage on all varieties of citrus and particularly on early and mid-season oranges and tangerines. They may be controlled by treating the trees and cover crop with benzene hexachloride; 3 lbs. of a wettable (6 per cent gamma isomer) material per 100 gals. of water or with dust (1 per cent gamma isomer) at 60 lbs. per acre. These may be mixed with wettable or dusting sulfur.

*Grasshoppers:* In groves where grasshoppers are expected to be a problem, it is possible to obtain considerable control by the use of judicious cultivation practices (consult Citrus Experiment Station). Where immediate control is necessary, either of these materials may be used: benzene hexachloride at 0.4 to 0.5 lb. of gamma isomer per acre; chlordane at 1.5 to 2.0 lbs. of technical chlordane per acre; and chlorinated camphene at 3.5 to 4.5 lbs. of active ingredient per acre. These materials may be mixed with wettable or dusting sulfur and applied either as dusts or sprays.

*Little fire ants:* In groves where little fire ants interfere with picking fruit, spray trunks and main branches 2 weeks before picking time with wettable DDT at rate of ½ lb. of actual DDT per 100 gals. of water. With 50 per cent wettable DDT this requires 1 lb. of the material. Keep DDT sprays away from leaves as much as possible, as DDT will kill ladybeetles and other beneficial insects if leaves are covered, and may bring out increases of scales and mites.

*Other species of ants:* Ants nesting around the base of a tree may be killed by mixing a small amount of a 5 per cent chlordane dust with the top inch of soil over the anthill. Then spread an additional amount over the surface of the soil around the base of the tree. Anthills in the middles may be treated by applying a small amount of dust over the anthill.

*Pruning:* Experimental data show that when the trees are reasonably free of dead wood, more effective control of melanose by copper applications is obtained. This is especially true with regard to wood that has been recently killed, and consequently, pruning to keep the trees reasonably free of dead wood is an important part of a melanose control program. In bearing trees removal of water sprouts and limbs touching the ground will slow up scale spread and simplify spraying.

It is evident from perusal of the foregoing Schedule B that: (1) the principal insecticides in general use in Florida are petroleum oil, lime sulfur (liquid and dry), sulfur as wettable or as dust, and DN (dinitro-*o*-cyclohexylphenol) as wettable or as dust with sulfur; and (2) that most of the insecticides are applied as sprays.

The petroleum oils in general use in Florida range from 70 to 100 sec. Say. viscosity, with an unsulfonated residue of from 75 to 85 per cent. Oils of both a paraffinic and a naphthenic base are used. It is probable that the use of paraffin-base oil predominates. Only a relatively small amount of the more highly refined oils, that is, 90 to 95 per cent unsulfonated residue, is employed. The oils are used both as stock emulsions and as tank mixtures. June and July constitute the preferable time for using oil sprays to control scales, with least adverse effects on the trees and fruit. (W. L. Thompson, from correspondence). Besides conventional spray and dust equipment, ''speed sprayers'' are used extensively in Florida for the application of various spray materials on citrus trees.

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# CHAPTER XV

# QUARANTINE AND QUARANTINE SERVICE

BY

HARRY S. SMITH

## THE PURPOSE OF PLANT QUARANTINE

THE SOLE purpose of plant quarantine is to protect agricultural areas against the introduction and establishment of plant pests and diseases from which they are free. Many pests and diseases are more or less specific in their action; that is, they attack only certain groups of related host plants. Therefore, when a cultivated plant is introduced into a country where no near relatives occur, naturally it is likely to be fairly free from serious pests and diseases, the native insects and diseases being in large measure unable to adapt themselves to such hosts. This desirable condition has not, as a rule, been maintained for any great length of time in any particular locality, for the reason that extensive commerce in nursery stock and other commodities on which pests and diseases may be carried has resulted in the introduction and establishment of many of them.

In the most important citrus-producing areas of the world the genus *Citrus* is itself an introduction, but we find that the major pests and diseases of this plant are common to many of the citrus-producing areas as a result of their dissemination through human transport. The California red scale, *Aonidiella aurantii* (Mask.); the Florida red scale, *Chrysomphalus aonidum* (Linn.); the purple scale, *Lepidosaphes beckii* (Newm.); the citrus mealybug, *Pseudococcus citri* (Risso); the Spanish red scale, *C. dictyospermi* (Morgan); the citrus white fly, *Aleurodes citri* Ashm.; and the Mediterranean fruit fly, *Ceratitis capitata* Wied., occur rather generally in the important citrus areas, although many of them are free from one or another of these pests. The purpose of plant quarantine as advantageous to the citrus industry is to prevent the establishment of pests in the citrus-producing areas which are still free from them (Fleury, 1926).

It may reasonably be assumed that under primitive conditions, before the advent of agriculture and commerce, all forms of life had reached stability so far as their geographical distribution is concerned. A method of natural dissemination has always existed for every organism. Either it has been provided with some means of locomotion, such as the ability to swim, crawl, or fly, or it has been carried about by some agency which moves from place to place. It may be carried, for example, by other animals or plants, or by air (Quayle, 1916) or water currents.

These agencies of natural distribution are not universally operative, and often are nullified by barriers. Barriers which tend to counteract natural dispersal are of various types, but may be classified in three general categories: topographical, climatological, and biological. A topographical bar-

rier may consist of an ocean, a high mountain range, or a desert which an organism is unable to traverse. A climatic barrier may consist of a zone or an area which an organism is unable to cross because of unfavorable meteorological conditions such as heat, cold, humidity, or aridity. A biological barrier may consist of a zone or area which an organism is unable to cross because its food plant or host is not present there (Orton and Beattie, 1923).

All organisms also have certain environmental requirements which must be present in a locality before they can exist. For instance, plants require certain soil or water conditions or a special type of climate. In their geographic distribution, animals are limited to areas where their particular kind of food exists, and the like.

We have, then, three factors which determine the natural distribution of organisms: means of locomotion, barriers, and fitness of the environment for the existence of the particular species. Effectiveness of the natural means of locomotion varies greatly among species. However, because of the long periods of time through which it has had an opportunity to act, a species has always been able to distribute itself from its point of origin to all localities where the environment is suitable for its existence, *except where natural barriers have intervened.* It follows from this that there are many areas on the earth where a species *could* thrive, the environment being favorable, but in which it does not exist because its natural means of locomotion has not been such as to enable it to surmount the barriers which keep it out. Man, with his development of methods of transportation, has provided a means of breaking down these natural barriers; and, unless steps are taken to prevent it, the ultimate effect of man's influence will be that each species will occupy all parts of the earth's surface which are environmentally favorable to its existence. The development of plant quarantine is an attempt to prevent these consequences so far as pests and diseases of plants which are useful to man are concerned (Smith *et al.*, 1933).

## PRINCIPLES AND LIMITATIONS OF PLANT QUARANTINE

Factors, then, which have an important bearing on the possibilities and the development of plant quarantine are: the existence of barriers; the environmental limitations of species; and the nature and habits of the pest or of the disease-producing organism, such as the number of kinds of plants affected, the part of the plant affected, whether the affected part is transported in commerce, and whether the pest or disease may be carried in commodities other than the host or separately from the host.

In general, living plants or parts thereof (nursery stock, bulbs, tubers, roots, cuttings, etc.) form the most dangerous carriers of pests and diseases; but, when only certain parts of the plant are attacked, other parts may be transported safely in commerce. For example, the citrus white fly is not transported on the fruit, but only on the leaves of the host plant; therefore, fruit from an area infested by white fly may be admitted safely to an area free from this pest. The Mediterranean fruit fly attacks only the fruit; hence citrus nursery stock from an infested area could safely be admitted into an

uninfested area, but not with soil on the roots, since this pest pupates in the soil. It is obvious, then, that an intimate knowledge of the biology of a pest or disease is fundamental to the devising of quarantine measures to prevent its spread.

It is undoubtedly true that the exclusion by quarantine of every individual insect or disease-producing organism from an area is often a practical impossibility. However, this does not necessarily make a quarantine against it ineffective or unjustifiable. It is not ordinarily a simple matter for an insect pest or plant disease to become established in an area previously free from it, even though it occasionally slips through the quarantine line. Usually, a complicated set of conditions must exist before an introduction can result in the permanent establishment of a pest or disease.

Among the requirements that must be fulfilled if an introduction is to result in the permanent establishment of a species are the following: special conditions for the infection of the host plant, such as wounds or abrasions, must sometimes exist; sometimes the organism must arrive only at a certain season; the introduction must usually occur in the immediate vicinity of the host plant; species which require alternate host plants, such as white pine blister rust, must be introduced into a locality where both host species occur; with a few exceptions the insects brought in must be fertilized females, or both sexes must be admitted simultaneously if fertilization is to occur; the organism must be introduced in sufficient numbers to insure that at least a few will persist after unfavorable climatic conditions, host resistance, and the attack of enemies have taken their toll. In general, then, it will be seen that the chances are usually against successful establishment by the introduction of a very few scattered insects or plant-disease organisms. This fact has been well demonstrated experimentally where the purposeful introduction of plant-feeding insects has been attempted, as for example the introduction of insects into Hawaii to control the weed *Lantana,* and into Australia to control prickly pear (Smith, 1930).

That introductions so often fail to bring about the permanent establishment of pests and diseases in new habitats is of fundamental importance to plant quarantines. It is manifestly impossible to prevent *every introduction* by legal restrictions; but, if introductions happen frequently enough, or on a sufficiently large scale, sooner or later the right combination of circumstances will occur and establishment will result. Plant quarantine can make these introductions so infrequent, so scattered, or so infinitely small that establishment will be either greatly deferred or prevented altogether.

The establishment of a pest or disease in a locality previously free from it does not necessarily mean that it will become economically important there. Climatic conditions, such as amount and seasonal distribution of rainfall, humidity, fogs, and degrees and range of temperature have a great deal to do with the abundance of pests and the virulence of plant diseases (Stevens, 1917). A pest or disease which in some parts of the world is of major importance on citrus may become established in other areas where citrus is an important crop and be of no economic importance whatever; for example,

citrus melanose, which is a disease of great destructiveness in Florida, has no economic significance in California, undoubtedly because California summers are rainless whereas in Florida the warm weather is accompanied by rainfall. Citrus scab, apparently, is another such example (Peltier and Frederich, 1926). There are many parallel examples among insect pests. The black scale is a serious pest of citrus in southern California except in the desert areas, but never causes damage on citrus in the interior sections of central California. The citricola scale thrives in the arid interior sections but does no damage in the fog belt, whereas the opposite is true of the purple scale. The cause of these peculiarities is undoubtedly climatic. Competition and attack by enemies also influence the abundance of pests, and an excessive number of insects established in new habitats is very often due to the fact that their insect enemies were left behind when the introduction took place.

No method has been developed by which it can be ascertained positively in advance whether environmental conditions in a new habitat are favorable or unfavorable to a given pest or disease, but the evidence is sometimes so conclusive as to leave no reasonable doubt. Strong indications that a pest or disease would not thrive in a given locality would seem to cast doubt on the advisability of taking quarantine action against it unless the pest or disease is particularly destructive, or unless the quarantine requirements are of such a kind as to cause little or no economic disturbance. In the practical application of quarantine, however, it must be recognized that frequently the environmental requirements of an important pest or disease are not sufficiently well known to permit accurate prediction of its adaptability to a given locality. When the desired knowledge is lacking, it would seem unwise to permit the entry of material likely to result in its introduction.

Many diseases and pests have more than one host. A knowledge of host relations is therefore a prime essential if quarantine action is to be sound. It is obviously futile to quarantine against some carriers and permit the entry of other carriers of the same pest or disease originating in the infested area.

As we have noted, the natural disseminative powers of a plant pest or disease are such that, given sufficient time, it will establish itself in all those areas where environmental conditions are suited to its existence, except those from which it is excluded by natural barriers over which it is unable to pass except by human transport. Natural barriers are therefore of great importance in relation to the development of plant quarantine.

The natural barriers may be absolute or partial, according as they prevent or only retard the natural dispersal of a given organism. Since dispersal across an absolute natural barrier is possible, theoretically, only through human agency, the spread of pests and diseases across it is subject to control of man. High mountain ranges are ordinarily traversed by relatively few passes through which commodities and vehicles may enter the area that is to be protected from invasion. A wide expanse of desert large

enough to form a natural barrier is usually traversed by only a small number of arterial highways. A seacoast usually has few seaports through which dangerous material might enter. Great distance itself is a natural barrier, but only a temporary one. Plant quarantine may sometimes be used justifiably where a distance barrier exists, but it must be borne in mind that a delay in the invasion is all that can then be hoped for, and hence that extreme restrictions under such conditions are of doubtful advisability. Furthermore, when distance is the only barrier, a serious difficulty is the fact that the transportation lanes between infested and noninfested areas are often exceedingly numerous and consequently almost impossible to patrol satisfactorily.

Since the efficacy of quarantine measures is so much influenced by the nature of dispersal, the methods by which pests and diseases may gain access to areas previously free from them are of great interest and importance. So far as quarantine is concerned, dispersal may be somewhat arbitrarily divided into two categories: local and long-distance. Local dispersal is brought about largely, but not entirely, by methods of distribution which are not due to man's activities. It includes natural locomotion by flight and crawling; the effect of wind, not only on flying insects but also upon wingless forms such as newly hatched scale insects, young gipsy-moth caterpillars, red spiders and mites, and on fungus spores and bacteria; carriage of young insects and pathogenic organisms by birds, on their feet and on nesting materials; carriage by other forms of life; and transportation by running water. Local dispersal is also brought about by man's influence, and it is reasonable to include in this category the purely local movement of teams, wagons, orchard and farm implements, and the local, noncommercial transportation or exchange of plants through ignorance or deliberate evasion of quarantine rules when such are in force (Butler, 1917).

Long-distance dispersal takes place entirely as a result of man's activities, mainly through the transportation of commodities such as nursery stock, fruit, vegetables, other plants or parts thereof, lumber, stone, or soil. Many pests, such as beetles, may be transported in vehicles or in commodities with which they have no biological relations but into which they have found their way accidentally. However, *the short-distance spread of a pest or disease cannot ordinarily be prevented, or even appreciably retarded, by quarantine action.* Man has little or no control over the agencies which make natural dispersal possible, such as flight and wind, and hence is powerless to prevent it. Short-distance spread due to man's influence would theoretically be subject to control, but ordinarily this is not feasible on account of the great expense and the extreme inconvenience and irritation resulting from such attempts. Regulations can be promulgated that will make it unlawful to transport plants locally, but their enforcement is possible only in situations of extreme seriousness, as, for example, in connection with an eradication campaign.

Natural dispersal, and even short-distance spread, may presumably be retarded by intensive control measures, which often would be more effective

than regulations designed to prevent the local transportation of host plants since the rigid enforcement of these regulations is impractical. Intensive control seems to have been effective in connection with the citrus white fly in northern California, where it appears that control measures originally designed merely to prevent or delay the spread have not only accomplished that purpose but ultimately will result in complete eradication of the pest.

Quarantine can be used, though rarely, to prevent short-distance spread. In the eastern United States, an effort is made to bring about annual eradication of the gipsy moth, a nonflying insect, over a zone about thirty miles wide at the western boundary of the infested area, this distance being greater than the probable limits of annual natural dispersal. Thus far, the moth has been held east of this zone.

Temporary artificial barriers, in the form of nonhost zones, are practical against pests or diseases having only a single host plant or a very restricted host list. They have been used successfully against the pink bollworm of cotton in the United States.

Such restrictions are sound enough, provided they are based on a sufficiently full biological knowledge of the pest or disease they are designed to combat. It must be admitted, however, that the expense and inconvenience entailed in carrying out this type of regulation are such as to make it applicable only in extremities. Ordinarily, regulations designed to prevent the purely local movement of commodities and appliances deemed to be carriers of a pest or disease are difficult to justify when it is recognized that natural dispersal, not subject to control, will in all likelihood distribute the pest or disease over the same area in about the same time, irrespective of the regulations.

With the exceptions mentioned, quarantines are of real value only when supported by natural barriers which prevent or greatly retard natural dispersal and which are of such a nature as to limit the number of transportation lanes, making the control of human carriage more easily effective.

## METHODS OF ENFORCING PLANT QUARANTINE

*Inspection at point of delivery.*—Several systems have been used, or have been suggested, for preventing the establishment of pests and diseases in areas free from them. Probably the first method used was inspection at the point of delivery of imported material deemed to be carriers, and rejection of any material that might show signs of infestation or infection. This method is still in use in many places. It may occasionally be effective where the pest to be excluded is large and conspicuous, or where the material is very limited in quantity. However, it has been repeatedly demonstrated by experience that it is impossible to prevent the introduction of most pests and diseases in this way. Not only is it physically impossible to examine any great amount of such material with the necessary care, but it is often impossible to detect the presence of disease even with the most minute examination; most plant-feeding insects which are likely to be transported on nursery stock or fruit have certain stages which are inconspicuous or hidden and are

not therefore easily detected. With respect to many pests, inspection of every part of a plant, perhaps even with a microscope, would be required to enable an inspector to say positively that it was free from infestation. This is particularly true for scale insects, the young of which have a habit of secreting themselves beneath bud scales or bark. In their early stages, many boring insects can be detected only with great difficulty; also such fruit-infesting insects as the Mediterranean fruit fly, the Mexican orange fly, and others.

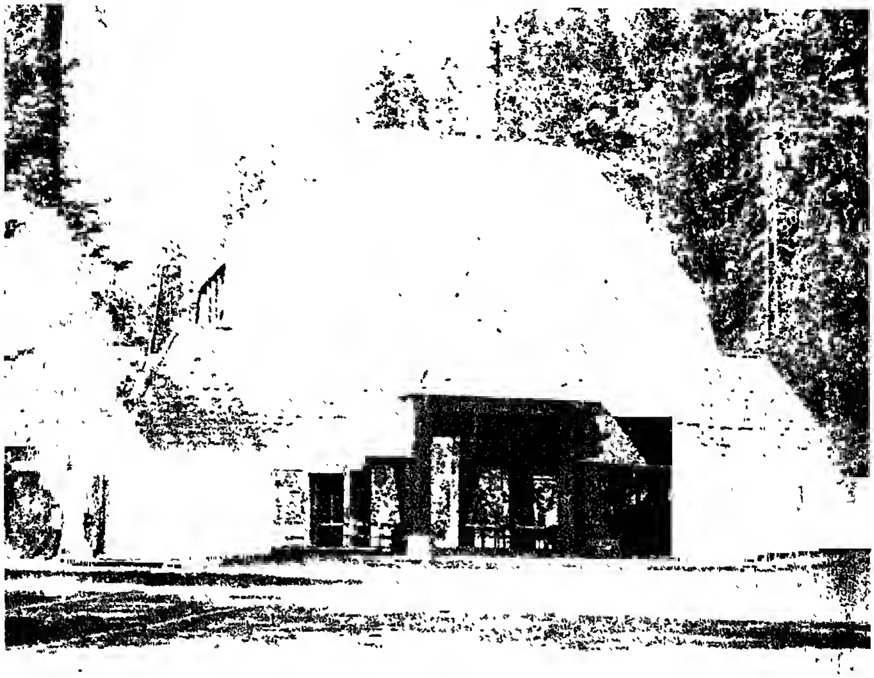

Fig. 262. California State Border Quarantine Station, Redwood Highway, California-Oregon line. (Courtesy California State Department of Agriculture.)

Relatively few insects are so conspicuous when occurring on nursery stock as to make the necessarily cursory inspection of commercial shipments a reliable safeguard against infestation. As for plant diseases, a considerable time, sometimes two or three years, must elapse before conspicuous symptoms appears on the host. The pathogenic organism may be present and the infection be well under way without external evidence of its presence. It is of course a practical impossibility to inspect for such diseases.

It is not maintained that such inspection is entirely valueless. Certain conspicuous pests could be excluded by this means. Perhaps careful inspection of all incoming material and rejection of the entire lot on the first indication of infestation might somewhat delay the entry of the pest. Inspection might perhaps be justified as a protection against minor pests and diseases.

And it may be argued that inspection yields valuable information on the geographic distribution of pests and diseases, upon which quarantines may be based; but as against invasion by dangerous pests and diseases a sound quarantine program will not ordinarily permit host plants or fruits which originate in the infested area to pass into a clean area merely on condition that inspection fails to reveal infestation or infection. Instead, quarantines should prevent the passage across the quarantine line of all hosts of a prohibited pest or disease. Such fruits and plants should be declared contraband, and inspection should be limited to the search for and proper disposal of such contraband. Only where the material can be treated, as will be discussed later, can this requirement be avoided.

This conclusion, it should be pointed out, does not lessen the necessity of an inspection service. Inspectors are essential to prevent the entry of contraband material.

*Inspection at point of origin.*—Another system which has been employed in some degree is the inspection of shipments and their certification at point of origin, certification being accepted in lieu of inspection at destination. Various plans based on this system have been proposed for international action. The most pretentious of these was that drawn up at the International Phytopathological Conference held in Rome in 1914 (Butler, 1917). At this conference it was decided that each member state was to set up an organization charged with the responsibility of inspecting consignments of nursery stock intended for export and of supplying certificates to the effect that the stock was free from certain pests and diseases. The certificate was to serve to admit inspected stock into the countries signing the agreement. For several years, as a condition of entry of European plants into the United States, the Federal Horticultural Board had tested the policy of relying on certification, at point of origin, of freedom from infestation. When the reliability of the point-of-origin inspection was checked by inspection at destination, it was discovered that large numbers of plants infested with scores of pests and diseases were coming in even though they bore certificates attesting to their cleanliness. For this reason, the United States could not agree to the recommendations of the Rome convention, and the system proposed has never come into general use. The objections to this plan, which are the same as those raised concerning inspection at destination, are based on the practical impossibility of detecting the presence of many plant pests and diseases on shipments of propagating or other plant material.

*Use of embargoes.*—An alternative to the inspection system is the use of embargoes, that is, the absolute exclusion of certain material from the area to be protected. While embargoes, in conjunction with natural barriers, would effectively prevent the entry of dangerous pests and diseases, a serious objection to this method is its interference with trade. General use of complete embargoes would result in a condition of economic isolation which would be more of a detriment to both producers and consumers than any major pest or disease. It is necessary, therefore, to seek a compromise method which will possess most of the safety features of the embargo and yet will permit

the conduct of interarea trade. This requirement can be most satisfactorily met by the adoption of a system of controlled introduction of agricultural commodities under embargoes.

Under such a system, which can be justified only when natural dispersal into the protected area is prevented by barriers, a general control is set up over all incoming plant material. The plants and parts thereof, including fruits and vegetables, are permitted entry on condition that one of the following requirements is met: (1) The commodity is not deemed to be a carrier of a major pest or disease which, there is reason to believe, would do serious damage to an important crop in the area to be protected. (2) It originates in an area where such pests or diseases are believed not to occur. (3) It has been produced and packed under such conditions as to preclude danger of infestation or infection. (4) It has been or may be subjected to treatment which will destroy live infestation or infection. Certification at point of origin indicating compliance with requirements 2, 3, and 4 is sound, provided the organization issuing the certificate is reliable and has facilities for obtaining dependable data or otherwise carrying out the requirements. This, unfortunately, is not always the case (Smith *et al.*, 1933).

The system of controlled introduction under embargoes is applicable, it will be seen, only to pests and diseases of known economic importance. It must be recognized, however, that many major insects and diseases have been relatively rare and unimportant until transported out of their native habitat. The cottony cushion scale, citrophilus mealybug, Japanese beetle, chestnut blight, and citrus canker were practically unknown until they were introduced into the United States. There is not the slightest doubt that in many parts of the world there are other insects and diseases which, if established in a new habitat, would become of serious economic consequence. There is no way of knowing what these are or where they may occur. Protection against them is possible only so far as a political unit is willing to make itself independent of commerce in plants and plant products with other political units.

## ERADICATION FOLLOWING ACCIDENTAL INTRODUCTIONS

It is possible to exterminate a major pest or disease after it has gained a foothold in a new habitat; several examples are now on record which demonstrate the practical feasibility of such attempts. Eradication can be looked upon as the second line of defense against the permanent establishment of pests and diseases in areas formerly free from them. In Florida, both the Mediterranean fruit fly and the citrus canker have apparently been exterminated.

*Eradication of Mediterranean fruit fly.*—According to Quayle (1938, pp. 237–240),[1] "The Mediterranean fruit fly was discovered near Orlando, Florida, on April 6, 1929. Steps were immediately undertaken for a campaign of eradication. On April 15 an emergency fund of $50,000 from the previous Florida legislature was released for immediate use. On April 17, the U. S.

[1] Quoted by permission of the Comstock Publishing Company, Ithaca, New York.

Department of Agriculture made available $40,000, which was transferred from the pink bollworm appropriation. On May 2, a Federal appropriation of $4,250,000 was made for the campaign, and on June 7 the Florida legislature appropriated the sum of $500,000 for the same purpose.

"In the meantime the campaign was planned and work was prosecuted vigorously. Wilmon Newell, Florida State Plant Board Commissioner, was placed in charge of the campaign for the U. S. Department of Agriculture and for the State of Florida. C. L. Marlatt was chief of the Plant Quarantine and Control Administration, the agency directly responsible for the United States Government.

"The state was divided into, (a) *Infested Zones,* which included the area within one mile of any property in or on which infestation had been determined; (b) *Protective Zones,* which included the area within nine miles of the outside boundary of any infested zones.

"There were departments of Inspection, Prevention of Spread, Spraying, Labor and Equipment, Publicity, Permits, *et cetera,* and a Research Section in charge of A. C. Baker, of the U. S. Bureau of Entomology, with divisions of Host Plants, Insecticides, Identifications, Traps, Baits, etc.

"In 1929 a host-free period was maintained, which began on May 1 and continued to October 1. Prior to this period the regulations required the shipment, destruction or processing of all ripe or ripening citrus fruits growing within the protective zones and prohibited the planting or growing of vegetables that would mature or reach the stage of susceptibility during the host-free period. The only host fruits or vegetables permitted to grow or exist in the protective zones at any time were citrus fruits on the trees in such stage of immaturity as not to be susceptible to infestation, and host fruits and vegetables in storage or on retail sale for immediate consumption. Robbed of fruits in which to lay their eggs and multiply, any carry-over of the insect would have to be by means of adults originating before the host-free period was inaugurated . . .

"To prevent against any carry-over of adults, poisoned bait sprays . . . were used throughout the infested area. . . . Small quantities were sprayed on the foliage of wild and cultivated plants at regular intervals. Some idea of the magnitude of the spraying program of 1929 may be gained from the following amounts of materials that were used.

| | |
|---|---|
| Sugar | 2,218,387 pounds |
| Lead arsenate | 299,309 pounds |
| Syrup (molasses) | 375,301 gallons |

"Official forces sprayed as high as 110,000 acres a week, and roadside spraying amounted to the equivalent of one spraying along 18,554 miles of highway. To do this work of eradication the following machinery was used:

| | | | |
|---|---|---|---|
| Trucks | 187 | Trailers | 19 |
| Tractors | 92 | Stubble shredders | 30 |
| Sprayers | 60 | | |

In one month of the campaign there were 6,300 names on the labor payrolls.

"The area within which infestations of the fly were found was designated as the 'Eradication Area' and this embraced about 10,000.000 acres, or between 15,000 and 16,000 square miles. Within this area was located 72 per cent of the bearing citrus trees of the state, or 120,000 acres of citrus and 160,000 acres of other fruits and vegetables.

"After August, 1929, a light infestation was found on November 16. This infestation was destroyed and the locality remained free. In December, 1929, the United States Congress appropriated $1,290,000 for the work of inspection and for crop movements. On January 11, 1930, all eradication work was discontinued on account of lack of funds. On June 7, 1930, the United States Congress appropriated $1,740,000 for continuation of inspection and certification and $1.500,000 for emergency eradication work. The total expenditure from state funds to December 31, 1930, was $381,475.95; and the total expenditure to the same date of Federal funds was $6,858,636.95.

"On March 4, 1930, another slight infestation was found near Orlando, which was destroyed and there was no recurrence of the fly. On July 25, 1930, two pupae were found under a sour orange tree in St. Augustine and measures were taken at once to destroy this focus of infestation.

"On November 15, 1930, the Secretary of Agriculture lifted all quarantine restrictions on Florida products on account of the Mediterranean fruit fly, which had been effective since May 1, 1929.

"No evidence of the fly has been seen in Florida since the last record given above, on July 25, 1930. The known period of existence of the fly in Florida was thus 14 months. . . .

"That is the story, as briefly as it may be told, of the history of the most remarkable achievement in the eradication of an insect."

*Eradication of citrus canker.*—According to Rhoads and DeBusk (1931, p. 40): "Canker is the worst disease of citrus trees that has ever been introduced into the Gulf States and, had it become well established in Florida, it would undoubtedly have caused disastrous results to the citrus industry. Fortunately, the serious nature of this disease was early recognized and sufficient sentiment was created to undertake its complete eradication. Between 1914 and 1931 more than $2.500,000 of state, federal, and private funds were spent in combating citrus canker in Florida alone and the total cost of this disease to the state thus far has been at least $6,500,000. During this period 257,745 grove trees and 3,093,110 nursery trees were destroyed incidental to the eradication of this disease, which occurred in 515 properties scattered through 26 counties. Through the effective control campaign and systematic inspection of grove properties carried out by the State Plant Board, it appears that canker has been eradicated in Florida. As a result of this energetic campaign, there has been no commercial damage to Florida citrus groves by this disease since 1922, and no infections have been found since 1927. The apparently complete eradication of this dreaded disease from Florida, Alabama, and Mississippi is one of the most outstanding accomplishments in the history of plant disease control. Constant vigilance is necessary, however, to be sure that the disease does not obtain another foothold."

Since the foregoing was written, no further infections of citrus canker in Florida have been found. Occasional infected dooryard trees have appeared in noncommercial areas of Louisiana and Texas, but the Federal Bureau of Entomology and Plant Quarantine, in coöperation with the states concerned, is continuing the survey and control work, and it is confidently expected that this will result in the ultimate eradication of this disease from the continental United States.

These two demonstrations of the soundness of the principle of pest and disease eradication were epoch-making events in the development of plant protection. Their importance cannot be overestimated. Had not the Mediterranean fruit fly and citrus canker been eradicated from Florida, they undoubtedly would have spread, with disastrous consequences, to many if not all parts of the United States where their hosts are grown.

Several incipient outbreaks of the gipsy moth, pink bollworm of cotton, and the white fly of citrus have been eradicated.

*Where eradication can be used.*—The possibility of exterminating an introduced pest or disease if its presence is discovered before it becomes widespread greatly increases the practical importance of the plant-quarantine policy. Plant quarantines, regardless of how efficiently they may be enforced, may in time permit the introduction and temporary establishment of a pest or disease. Some avenues of entrance cannot be closed for economic reasons, and methods of entrance unrecognized by the quarantine authorities may exist, or mistakes may be made by inexperienced personnel. Even the most carefully drawn and efficiently administered quarantine may develop a leak through which a pest or disease may enter the protected area and become established. The occasional failure of quarantine to prevent the limited establishment of a pest or disease does not exclude the possibility of preventing *permanent* establishment, if discovery of the pest or disease is followed by a well-directed campaign aiming at eradication of the invader.

In recent years the public has come to recognize the dangers of introduced pests and diseases and in general is inclined to support requests for authority and funds to be used for eradication purposes. Without question, there are many introduced pests and diseases against which it would be inadvisable to attempt an eradication campaign. Whether or not such a program should be undertaken can be determined only after a thorough analysis of the situation in its economic, biological, and sociological aspects. When all three warrant it, there should be no hesitation in attempting complete extermination of the pest (Felt, 1922).

The most difficult aspect of such a problem is usually the biological. One of the first things that must be determined is the extent of the distribution of the pest or disease. The feasibility of eradication will usually depend materially upon the size of the area infested or infected. To undertake eradication without preliminary scouting to determine the limits of distribution would be foolhardy. The type of insect or disease, its disseminative powers, whether it is subterranean or aerial, the part of the host plant it attacks, how it may be transported by human agency, its seasonal history, its host

list, how it reacts toward different hosts and different climatic conditions, and many other points must be studied and their relation to the possibility of eradication determined. The essential thing is to search for vulnerable points at which the pest or disease can be attacked. In insects that attack only the fruit, such as the Mediterranean fruit fly, the theoretical requirements for eradication would be simple. The maintenance of a host-free period each year, long enough to prevent the issuing adults from laying their eggs, would fulfill the theoretical requirements. The citrus white fly attacks only the leaves of its hosts, and there is a period in winter when all the flies are in the immature stages on the leaves of evergreen hosts. Theoretically, defoliation of all host plants at this time would result in eradication (Mackie, 1931). Other insects, such as the European corn borer, which not only has many cultivated hosts, but breeds also in the stems of many species of weeds, would be extremely difficult to eradicate.

It is necessary to know an insect's life history in order to make an eradication campaign successful. Take, for example, the walnut husk fly, *Rhagoletis completa* Cress. The adult flies emerge from the ground in June and July and deposit their eggs in the green husks. The larvae mature, leave the nuts, and drop to the ground, where they pass the winter as puparia. A superficial knowledge of the life history of this insect would lead one to believe that all that is theoretically necessary for eradication is to remove all the nuts from the trees for one season, so that the adult flies would find none in which to deposit their eggs. Detailed studies of the habits of this insect, however, have revealed the fact that, from any one generation going into the soil, some individuals emerge the following spring, others the second year, still others the third, and some do not emerge until the fourth season after they have entered the ground! Instead of removing the nuts for one year, it would be necessary to remove them for four consecutive years in order to fulfill the theoretical requirements for eradication. Thus it will be seen that the specific habits of the pest have a very direct relation to the feasibility of eradication, and they must be understood in detail before action is attempted.

The availability of funds for defraying the cost of such projects is a first essential; but even with ample funds the work can hardly succeed unless there is a large enough body of public opinion favorable to it and willing to undergo certain inconveniences in order to make the campaign a success. Demonstration of the feasibility of eradicating major plant pests and diseases is the greatest contribution to economic entomology and plant pathology of the last quarter century.

## PLANT QUARANTINE AS AN AGRICULTURAL POLICY

A large item in the cost of production of the citrus crop is the expense of controlling pests and diseases. Many producing areas are, however, still free from some of the most important of these, and the desirability of keeping them out is scarcely a debatable topic. Their introduction and successful establishment would add still further to the cost of production and in some

places would perhaps even prevent the profitable continuation of the citrus industry.

Plant quarantines themselves, however, also have important economic and political consequences. In order to make quarantines effective it is necessary to place restrictions on the transportation of commodities; but restrictions of that kind are a source of expense, inconvenience, and ill-will, and sometimes result in serious curtailment or even in complete loss of markets for the products affected. The development of agriculture and horticulture in new countries and their improvement in old areas has resulted largely from the exchange of plant material between countries for the introduction of new varieties. If commercial traffic in fruit, cereal products, vegetables, and many other plant products is considered, it is easy to see that the barring from a country or a state of plant materials which constitute the principal carriers of pests and diseases cannot be effected without introducing many serious economic complications. The exchange of propagating materials and the world's commerce in agricultural products necessarily involve the possibility of introducing pests and diseases into clean areas. This problem, then, is one of determining how far it is possible to reduce the risk without placing ruinous restrictions on trade between localities.

In economic importance, plant pests and diseases vary all the way from mere nuisances to veritable plagues the control of which is vital to the industry affected. It would be economically ruinous to put into operation so comprehensive a quarantine program as would be necessary to protect a large area against the introduction of *all* pests and diseases; it would be equivalent to depriving the people of practically all exchange, with outside areas, of food and other plant products and thus would bring about a condition more intolerable than that occasioned by the pests and diseases. The question, then, is entirely one of judging which pests and diseases are to be excluded. The general policy has been to apply specific quarantines only to those pests and diseases which have already demonstrated their capability of causing serious damage, although it has been borne in mind that insects and diseases of no apparent significance may react in an entirely different way in a new environment—a risk that must be assumed, unless the political unit promulgating the quarantine is willing to submit to economic isolation so far as plant products are concerned.

A state or country must not adopt a standard for its quarantine policy which it is unwilling to have other states or countries apply to its own products. Ill-founded, unfair quarantines, and quarantines against minor pests or diseases, are likely to result in retaliation of some sort against the products of the political unit maintaining the quarantine. Most producing areas have several pests and diseases peculiar to themselves. If they insist on excluding or restricting the entry of products of another area because those products carry minor pests, they must expect to have the same rule applied to them and to find their own markets restricted for similar reasons. It is easy to see that such a policy could result in economic isolation and thus defeat one of the primary purposes of plant quarantine, which is to enable the grower

to produce and to market his product at a profit. Persons entrusted with the quarantine authority have a double responsibility: first, to prevent the introduction and establishment of dangerous pests and diseases; and second, to keep the markets open for the products of the commonwealth which they represent. It has been well said that plant quarantine is a two-edged sword, and this must never be overlooked.

To administer quarantines for the best interests of a state as a whole requires not only good judgment, but also a great deal of courage. Producers of a certain crop may in good faith demand extreme quarantines to protect them from some minor danger; but the quarantines may result in retaliation, not against their own product but against the product of some other group, and so the requests must be denied even though the quarantine officer may be accused of neglecting the interests of the first group. For this reason, quarantine officers should be supported by a board or commission representing all the major agricultural products.

Not only is it essential that specific plant quarantines be restricted to major pests and diseases in the interests of commerce, but it is particularly important that there be no adoption of quarantine measures for the accomplishment of ulterior purposes such as the exclusion of a product from a market in order to gain a trade advantage. This is one of the commonly heard criticisms of quarantine, and there is no doubt that on occasion it has been justified. A quarantine honestly enacted and conscientiously administered may, of course, incidentally result in the protection of certain commodities from outside competition and thus may seem to give support to adverse criticism. Intense pressure is often applied to quarantine officials for quarantines that will protect commodities from outside competition. There is no more certain way to break down the entire quarantine system than to use it as a pretext to cover up an ulterior motive; the practice is sure to result in retaliatory measures, with disastrous economic effects. In the United States the courts have held that such quarantines between the individual states are unconstitutional, on the ground that they are not a proper exercise of the police powers granted the states by the Constitution, but are actually attempts to regulate interstate commerce (Strong, 1926).

The use of the police power for preventing the establishment of pests and diseases carries with it the obligation to rescind quarantines when they no longer serve the purpose for which they were enacted. It is incumbent upon the quarantine officer to observe closely, at all times, the biological and economic conditions governing a quarantine, since these often change rapidly, sometimes in such a way as to render no longer justifiable a quarantine which was quite sound when first set up. The decision to maintain or to rescind a plant quarantine should be based solely on its efficacy in protecting valuable property from injury through the establishment of pests and diseases. This is a fundamental principle of plant quarantine, and if a state or country does not recognize this obligation, it cannot expect and rightfully demand fair treatment in this regard from other states and countries when conditions are reversed (National Plant Board, 1932).

As knowledge increases, protection against the introduction of pests and diseases can be achieved with less and less disturbance of trade. A great deal of research must necessarily be brought to bear on questions fundamental to the problem. More knowledge and less guesswork is needed about the factors which limit the geographic distribution, abundance, and virulence of plant-destroying organisms. There is no doubt that some quarantines are being maintained unnecessarily, to protect areas against pests or diseases

Fig. 263. Vacuum fumigator, Ventura County Agricultural Department. By developing methods of disinfesting citrus nursery stock the State of California has done much to eliminate plant quarantine barriers. (Courtesy California State Department of Agriculture.)

which could not possibly thrive in them. Greater knowledge would free trade from some of these restrictions. There is also a fertile field for research in the development of methods of treatment of plant products which will free them from live infestation and infection, so that they may be transported without risk into clean areas. Many restrictions, particularly on food products, which form the major part of commerce in agricultural commodities, could thus be eliminated.

Finally, the spirit of fair play in plant quarantine needs to be extended. The use of plant quarantines is no longer limited to a few states or countries. They have been adopted throughout the world, and interest in the subject is increasingly evident. Commerce in agricultural commodities cannot exist

without incurring some risk of pest and disease introduction. A state which ranks high in agricultural production, and for that reason has great need of protection against the introduction of pests, has by the same token a great need of agricultural markets for its products. Whatever standard of plant quarantine a state or country adopts against the products of other areas, it must expect, and be willing, that the same standard shall be applied to its own products. Quarantines designed to eliminate only slight risks may result in serious curtailment of its own markets. Quarantine officers in general have a full appreciation of this danger, but it is not always so evident among producers and shippers.

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## Chapter XVI

# INJURY BY RODENTS AND ITS CONTROL

BY

TRACY I. STORER

The rodents[1] are mammals of small size that feed mainly on plant materials. They possess, in the forepart of the jaws, two pairs of sharp, chisel-like incisor teeth which they use for gnawing. The principal rodents harmful to the citrus industry are: the pocket gophers (*Thomomys*, *Geomys*), which may girdle the trunks of the trees below the surface of the ground, and also the roots; the jack rabbits (*Lepus*), which, in Texas and California, sometimes eat the bark of tree trunks; the cotton rats (*Sigmodon*), which, in Texas, may girdle trees; and the meadow mice or voles (*Microtus*), which, in California, eat the bark, especially on trees adjacent to piles of prunings or in the midst of cover crops that afford natural harbor for the mice. In earlier years, the California ground squirrel (*Citellus beecheyi*) occasionally damaged irrigation canals by burrowing in the canal banks that were constructed of earth, but its numbers are now much reduced. Burrows of pocket gophers may also divert water, weaken the banks of smaller ditches, and contribute to erosion. The alien Norway and roof rats (*Rattus*) in and around packing houses nibble at stored citrus fruits, to obtain the seeds, and track mold spores about.

In Florida, the pocket gopher (*Geomys*) is known locally as "ground squirrel" or "salamander," whereas some ground squirrels (*Citellus*) of the Middle West are called gophers! The land tortoise (*Testudo polyphemus*) of Florida, often called "gopher," is a land reptile that makes large burrows. In citrus groves these holes are a nuisance and a hazard in which farm machinery may lodge or work animals be injured, and they may contribute to the death of young trees if dug beneath them. Rodents may do serious damage to citrus; prevention of damage, even at considerable cost, is therefore important for satisfactory and economical production.

## POCKET GOPHER

The pocket gopher (figs. 264–266) is a small, stout-bodied, short-legged rodent having at either side of its mouth an external fur-lined cheek pouch or pocket for carrying food and nest materials (but not earth). The small eyes and ears are on the top of the head. The back and sides of the body are covered with short brownish hair, and the tail is short and scantily haired.

*Burrows.*—The animal lives habitually in rounded subterranean tunnels constructed by itself; it seldom comes out on the surface, and never climbs. The tunnels are commonly about two inches in diameter, more or less parallel

[1] Some information for this chapter was obtained in letters from the following persons: in California, H. J. Webber, R. H. Gray, H. J. Ryan, H. J. Ramsey, Ethelbert Johnson; in Texas, W. H. Friend; in Florida, J. R. Watson. See also Storer (1947, 1948).

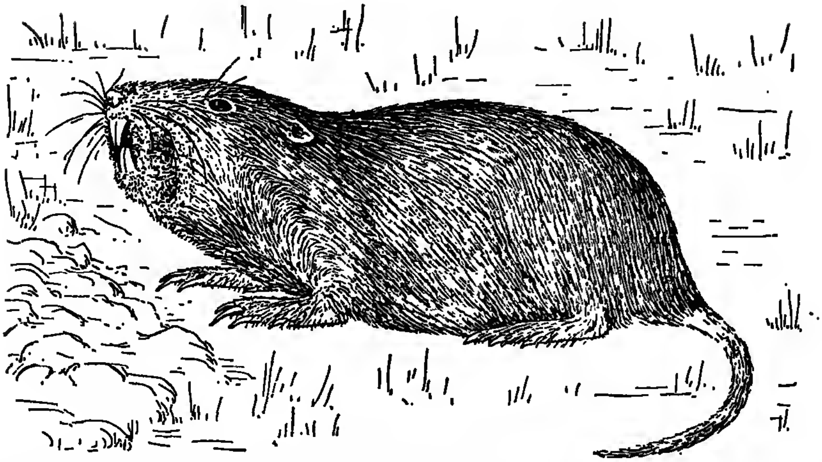

Fig. 264. Pocket gopher (*Thomomys*). Distinctive features are the blunt head, prominent incisor teeth, fur-lined cheek pouches, slender claws on the forefeet, and scantily haired tail. Head-and-body 6 to 8 inches long, tail 2½ to 4 inches.

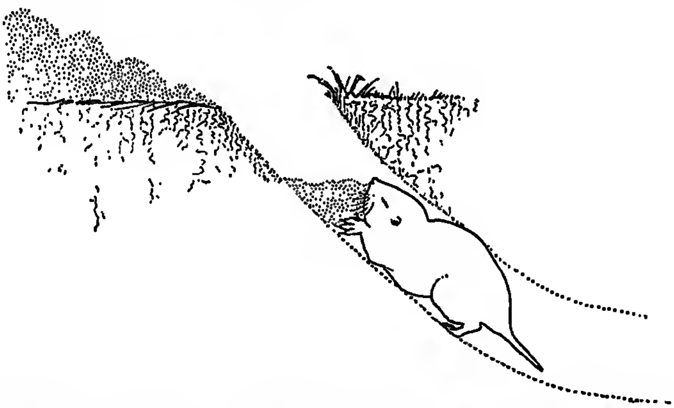

Fig. 265. Method employed by pocket gopher in pushing earth through a lateral tunnel and out upon the ground surface; mouth of lateral open during excavation. Compare figure 266.

to the ground surface, and usually at depths of six to fourteen inches. The burrows are deeper in soft or frequently tilled soils than in harder and undisturbed ones. Soil loosened by a burrowing gopher is usually pushed out onto the surface through short laterals made at frequent intervals along the main tunnels (but sometimes is packed in abandoned tunnels). There results a series of surface mounds which, by their position, often give a clue to the location of main tunnels. Successive loads are pushed out of a lateral so as to form a mound, commonly of crescentic outline; when the lateral is subsequently closed, a central depression in the mound usually indicates the loca-

tion of the mouth of the lateral tunnel. Besides the laterals used for pushing out earth, the gopher often makes short and nearly vertical laterals when it comes up to feed on surface vegetation. These are often closed with earth that does not rise above the adjacent ground surface.

The earth in fresh mounds is often darker than that of the surrounding surface because of its greater moisture content. Grasses or herbs covered by a mound become blanched by loss of chlorophyll in a few days, giving a clue to the age of the mound. Trapping is most productive in fresh mounds.

Gophers may dig deeper tunnels near their nests, and may also make "sumps" to drain the tunnels. Each nest chamber is about eight inches in

Fig. 266. Pocket gopher at mouth of a lateral tunnel, and loads of earth pushed out at various angles, producing a crescent-shaped mound with tunnel mouth centered in the crescent. Compare figure 265.

diameter and is filled with shredded grass and other plant fibers. Stores of food, chiefly of roots, are often found with the nests, or in separate, enlarged portions of the system. The below-ground system made by one pocket gopher may be many yards in length. Adjacent systems may be joined, but usually any connections are plugged off with earth. Ordinarily, each main system is inhabited by a single gopher, save when a female is rearing young. A system once cleared of its tenant gopher may, however, later be occupied by another, or may be used by a mouse or mole. Surface activity is less on dry areas during the heat of summer, when new mounds may be entirely lacking. Any dirt then moved by gophers is packed into existing tunnels. Little surface work is seen during and immediately after a heavy rain or irrigation while the soil is soggy, but soon thereafter activity may become noticeable. Few or no mounds are formed when the soil is hard and dry.

*Breeding.*—The rate of reproduction is low, usually one annual brood of five to six gophers on wild or uncultivated lands. The young are produced in the spring after rains have stimulated a new crop of green forage. There

are more broods on irrigated areas, especially in alfalfa fields, where breeding is almost continuous. In citrus groves where clean cultivation is practiced, forage for gophers is reduced in amount and probably lessens their rate of reproduction, whereas the growing of cover crops may encourage gophers and field mice.

The young gophers remain in the parental nest and tunnels for several weeks after birth, but eventually leave for an independent existence. Often they wander overland for some distance to start tunnels in new places; areas previously free from gophers may thus become infested. In citrus districts of southern California the young may be ready to disperse before April 1, and in the more northern areas by May 1. Adults also may occasionally move overland.

*Damage.*—Gophers feed on the roots, bark, and stems of plants and on some bulbs. They injure citrus trees by cutting small roots encountered in tunneling, and by gnawing off patches of bark on small or large roots and on the trunk itself below the surface of the ground.

Earth accidentally thrown against a trunk in the course of cultivation may encourage a gopher to work on the trunk. Damage of any sort may be severe before it is discovered. The injury is proportional to the amount of bark removed. If a trunk is completely girdled, the tree will soon die unless it is treated promptly and properly by inarching into the healthy trunk, just above the injury, seedlings planted around the base of the trunk, or by bridge-grafting twigs into healthy roots and trunk. (See chapter i for methods of inarching and grafting.) Even with any of these treatments the tree may fail to survive or to recover properly. Prevention of damage is, therefore, much more important.

In an early experiment with fertilizers at the Citrus Experiment Station at Riverside, a large planting, all on sweet stock roots, was made of alternate rows of navels and Valencias, every sixth cross row being of grapefruit. Gopher damage, then not fully appreciated, became extensive, but more of the navels were killed than of the other trees, sometimes all five in a plot row. Seemingly, the navel tops made the roots more attractive to gophers.

In Los Angeles County, it is estimated that an average of at least one tree in 50 acres is killed annually by pocket gophers; and since there are more than 50,000 trees valued at $25 each, the loss must total at least $25,000 yearly, to which should be added the losses of irrigation water and costs of control.[1]

Gopher burrows beneath or close to newly planted young trees will occasionally cause their death by drying out the soil. In any irrigated orchard the burrows divert or cause loss of water, sometimes contribute to breaks in ditch banks, and on slopes may contribute to erosion.

*Control.*—Fortunately, the control and elimination of pocket gophers is mainly a matter of effort and perseverance. No other common rodent is easier to control. Gophers may be greatly reduced in numbers, even on large areas; after which, a reasonably careful patrol, especially of the boundaries, will permit quick and successful removal of new invaders. As an example, one

[1] H. J. Ryan, letter, June 25, 1942.

large citrus ranch in southern California was practically cleared of gophers; then any new mound seen was reported immediately, by row and number of the nearest tree, and a trap set promptly. No opportunity was afforded for gophers to make a new start.

*Trapping.*—Trapping is especially well adapted to the work necessary in citrus orchards, and has the merit of showing when a particular gopher has been captured. Almost every large citrus ranch in California employs one or more men whose principal duty is to trap gophers. Discovery of even one mound within a grove or at its borders should be the signal to set a trap. Trapping is easiest and most effective in early autumn when the ground is

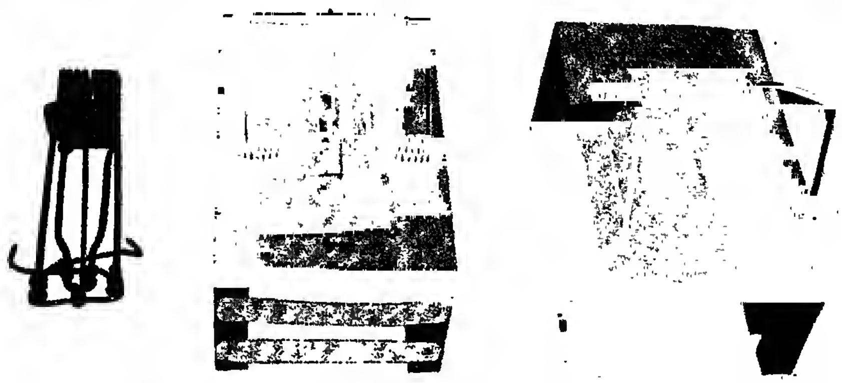

Fig. 267. *Left.* Macabee gopher trap. *Center.* Pocket gopher trap modified for capture of ground squirrels. *Right.* California pocket gopher trap.

moist, when gophers are quite active, and before breeding has begun; it is least effective in the dry midsummer period. The small size of the burrow, and the fact that gophers often move earth to fill an opened tunnel, preclude the use of rat or steel traps. Many special traps for pocket gophers have been marketed, but major choice has narrowed to two: (1) the Macabee, and certain adaptations of that type; and (2) the California box trap made of wood and having one or two choker loops (fig. 267). None has surpassed in effectiveness the original Macabee, an all-wire trap with two pointed jaws which are set apart on the tunnel floor. As the gopher comes along pushing its load of earth, the load touches an upright trigger pan set across the axis of the tunnel; this releases the jaw mechanism, which springs together and grips the gopher firmly and fatally. The box trap is set at the entrance to an opened tunnel, and the trigger is either baited with a prune or piece of carrot or left on the chance that the gopher will push against it. Explosive traps ("gopher guns") have been tried, but none has been permanently adopted, and some hazard attends their use.

The best "set" for the Macabee trap is in a main tunnel rather than a lateral. This requires two traps per setting, one in each direction, but results

are more certain and the catch, per trap per day, higher than when one trap is set in a lateral. The operator selects a fresh mound, notes the probable direction of the lateral by the position of the dirt-plugged hole, and probes with a slender rod or the long handle of a large iron spoon. The earth in the lateral is often loose and a probe can be pushed in easily to find the location of the main tunnel. Then by use of a shovel a hole is dug to expose the main tunnel in both directions, and any loose earth in the tunnel is removed. A trap is set well into each opening, and pressed down firmly so it will not slide when a gopher presses against the trigger pan. One end of a three-foot length of soft iron wire (No. 22 or 24) or stout cord is tied to the rear of each trap, and the other end is fastened to a stake driven near the set. The stake, preferably painted, should be tall enough to be found again easily. Many trappers close the burrow entrance with a clod of earth or tuft of grass so that practically all light is excluded. Traps should be examined at least once daily, preferably oftener, and reset if found sprung without a victim. After the gopher is trapped, the tops of near-by mounds should be leveled off, so that any subsequent burrowing in the vicinity will be seen at a glance.

One man using two traps per set can tend about fifteen traps an hour or seventy-five a day. On badly infested lands his catch may be as great as thirty-five or forty gophers a day. No citrus ranch, however, should allow gophers to multiply until large catches are possible.

*Poisoning.*—Control by poison serves well as a preliminary means of clearing heavily infested areas. Root vegetables cut and dusted with strychnine, or prunes in each of which crystals of strychnine have been inserted, are used. Poisoning should not be entrusted to irresponsible laborers. Containers used for mixing, and stocks of strychnine, should be plainly labeled POISON and locked up, out of the reach of domestic animals and of children. Nothing in the external appearance of prepared baits for pocket gophers will indicate that they are poisoned.

Formula 1: Cut baits (carrots or sweet potatoes), 4 quarts; strychnine (powdered, either alkaloid or sulphate), ⅛ ounce. Cut the vegetables into pieces about ½ × ½ × 1½ inches, dust on the dry strychnine (taking care not to inhale the dust), turning the baits repeatedly until all are evenly coated. Put into covered bucket and use at once. Label bucket and sifter: POISON.

Formula 2: Use dried prunes previously soaked 2 hours in water. With a slender knifepoint insert a few crystals of strychnine into each prune.

Baits so prepared are placed in the main tunnel of the pocket gopher by use of a special probe. This tool (fig. 268) is about 45 inches long. To a piece of ½-inch iron pipe 33 inches long, a bluntly conical tip of solid metal is welded, at one end, and a 12-inch length of ⅜-inch steel rod at the opposite end. The free end of the rod is forged to a carrot-shaped tip, ½ inch in greatest diameter. For loose or sandy soil the tip should be slightly larger, and for hard soil the rod tip should be merely tapered to a point. A side arm, 6 inches long, with collar and set screw, is clamped to the pipe shaft at a height suitable for applying downward pressure with either the hand or the foot.

The slender end of the probe is forced into the ground between a series of surface mounds. When it is pushed down, by pressure on the side arm, a uniform resistance will be met except when the probe enters a gopher burrow; then it will drop suddenly for about two inches. The tool is then reversed, and the hole reamed slightly so that poisoned baits can be dropped into the burrow. Two baits should be placed in each opening, and two sites in each tunnel system should be poisoned. After the baits are inserted, the operator closes each opening with his heel. The adjacent mounds should be trampled down or leveled off. Any new mounds will then indicate fresh activity.

*Flooding.*—Whenever citrus orchards are irrigated, pocket gophers present therein may be forced out by the water. If seen by the irrigator, they may readily be killed. A dog may help where gophers are numerous.

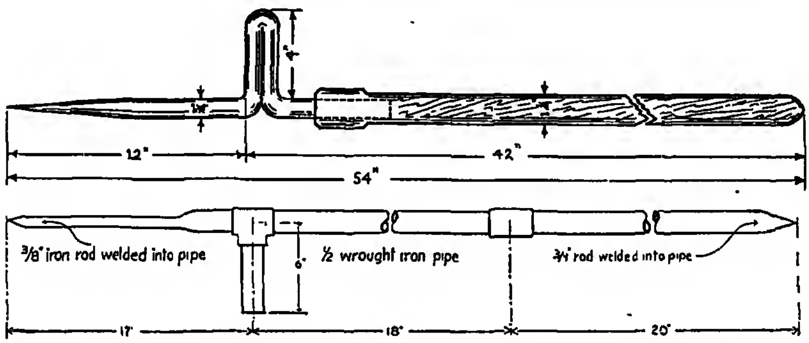


Fig. 268. Probes for locating main tunnels of pocket gophers and inserting poisoned baits. *Upper*, of steel rod with wooden handle; *lower*, of pipe with points forged into place.

*Gas.*—"Gopher bombs" that produce a poisonous gas have been marketed at times, but are not very successful. Hydrocyanic acid gas and carbon disulphide have been injected into gopher burrows, but the extended system of tunnels, their proximity to the surface of the ground, and the porous character of the soil in many plugs may render the use of gas unsuccessful. Furthermore, carbon disulphide may injure or kill a young tree if used near the roots.

*Natural enemies.*—The barn owl (*Tyto alba*) captures gophers at nightfall as they come to the surface in their digging and feeding operations. The gopher or bull snake (*Pituophis*) pursues the gopher in its own burrow. Both of these predators are beneficial in any citrus orchard and merit the fullest protection from the owner.

## HOUSE RATS

Two alien rodents now common in many civilized countries and harmful to man in various ways are the Norway rat (*Rattus norvegicus*) and the roof rat (*Rattus rattus alexandrinus*).

The larger Norway rat (fig. 269) lives chiefly at ground level and in the basement or first story of buildings. It also thrives out of doors, finding

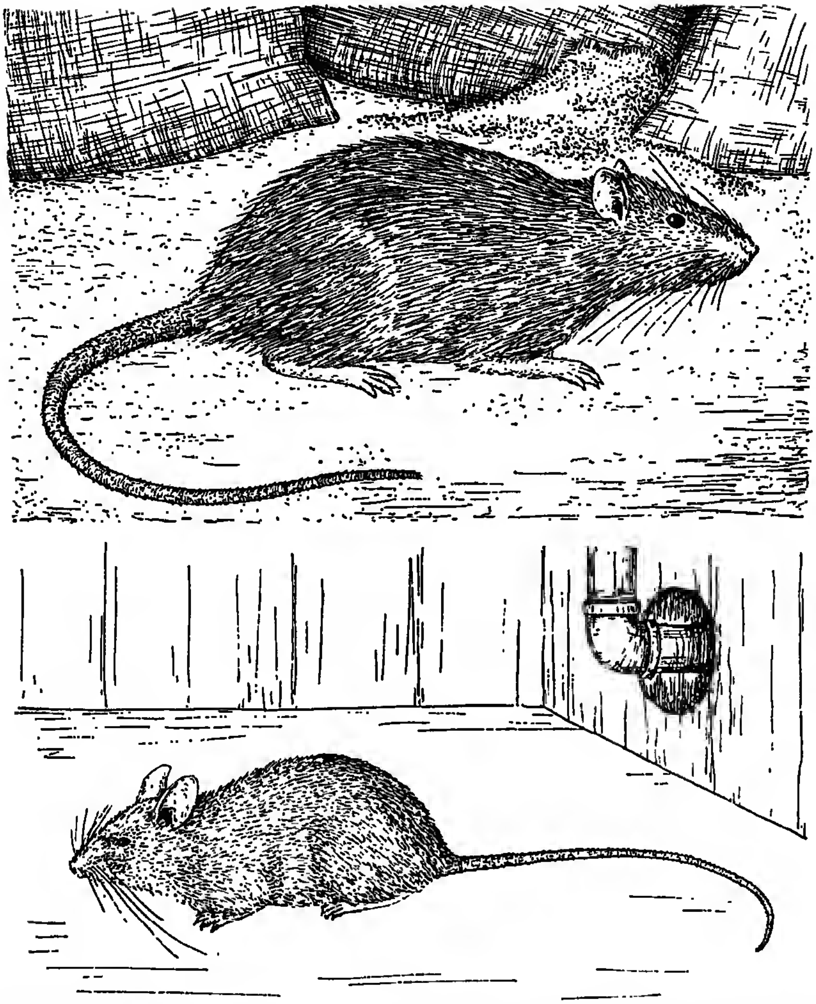

Fig. 269. The alien rats. *Above*, Norway rat; *below*, roof rat. The Norway rat has a blunt nose, smaller and slighlty haired ears, and tail usually shorter than head-and-body; it may weight as much as $1\frac{1}{2}$ pounds.

shelter under piles of lumber and trash, garbage heaps, and similar places. It will dig and occupy burrows in the ground. Since it averages eight young per brood and may have several broods per year, it can multiply rapidly in a new site and can soon replace losses in its numbers. The smaller roof rat also lives both indoors and outside; it climbs readily in buildings and on poles, conduits, electric wires, and similar structures. It multiplies a little less rapidly than the Norway rat and may be driven out by the latter's aggressions; yet it is common in many places.

*Damage.*—Both of these species of rats eat many kinds of foods, are clever at entering small holes or crevices, and make use of all sorts of shelter. They have not been reported as having injured citrus trees or fruits in orchards, but they do much damage in buildings by gnawing boxes or sacks and by feeding on cereals or other materials.

In citrus packing houses and storage sheds, rats are a nuisance because they damage oranges and especially lemons. They occasionally bite into sound fruits, and commonly seek boxes or piles containing rotten fruits, in order to feed on the seeds. Although the direct injury they do to marketable citrus is negligible, the rats in running about spread the spores of brown rot and other fruit-rot fungi (see chapter xi; also Fawcett, 1936, pp. 387–465) by smearing infected pulp on healthy lemons in storage. Losses from rotting are thereby increased in packing houses, and possibly in shipments as well.

*Control.*—The principal methods of rat control are exclusion, trapping, poisoning, and gassing. Special bacterial cultures ("rat viruses") applied on food baits to spread disease among rat populations have been employed in Europe, but their use in the United States is not recommended, and is prohibited in some states. Their effectiveness is doubted. "Carrier" rats often survive, and—which is more important—the bacteria used are similar to or the same as those producing disease or food poisoning in man. Reliance is therefore placed in other methods. Exclusion is the only proper means for solving the rat problem, since all others afford only temporary relief. Buildings must be so constructed and kept in repair that the rodents cannot enter. To exclude house mice and young rats, all openings in ventilators or around entering pipes and conduits, and all spaces between doors and floors, must be reduced until they measure less than three-eighths of an inch. Some means for effecting such ratproofing are shown in figure 270. Open ventilators and those with wide-spaced grilles can be covered with hardware cloth of ⅓-inch or ¼-inch mesh, securely attached on all sides. Spaces around pipes may be filled with concrete or covered by shields of sheet tin or iron. Fly screens on windows and doors give adequate protection if fitted closely and kept undamaged. Outside doors must fit closely over the floor or doorsills and must be kept closed when not in use, or mice and rats may enter buildings otherwise well proofed against them. Double walls and cork-lined refrigerator walls often harbor these rodents and must be inspected carefully at frequent intervals. Concrete floors with foundation walls extending 24 inches into the ground, and margined with an outward projecting base 12 inches wide, usually discourage rats from burrowing beneath. Corrugated sheet-metal walls and roofs are effective in excluding rats if the small spaces left at the ends of the corrugations are closed off. Trash, garbage, and prunings should be burned promptly, and lumber or empty boxes should be neatly piled and elevated a foot or more above the ground to reduce their attractiveness as shelter for rats.

Trapping eliminates small numbers of rats. The wood-based snap traps are best. They should be set along walls or beside other objects where tracks and droppings indicate the presence of the rodents. Raw meat or fish, rolled oats,

and bread or crumbs are common effective baits; only experiment will show which is best in any particular place. Traps should be examined and baits renewed daily; trapped rats should be removed as soon as possible. For "wise" rats it is sometimes desirable to bait an unset trap for several days to accustom the animal to feeding there before setting the trap.

Gassing and poisoning may leave dead rats to decay and produce bad odors in a building. A tight room or warehouse may be fumigated with cyanide or methyl bromide by operators competent in the application of such gases.

Some success has been achieved by dusting sodium fluosilicate along the

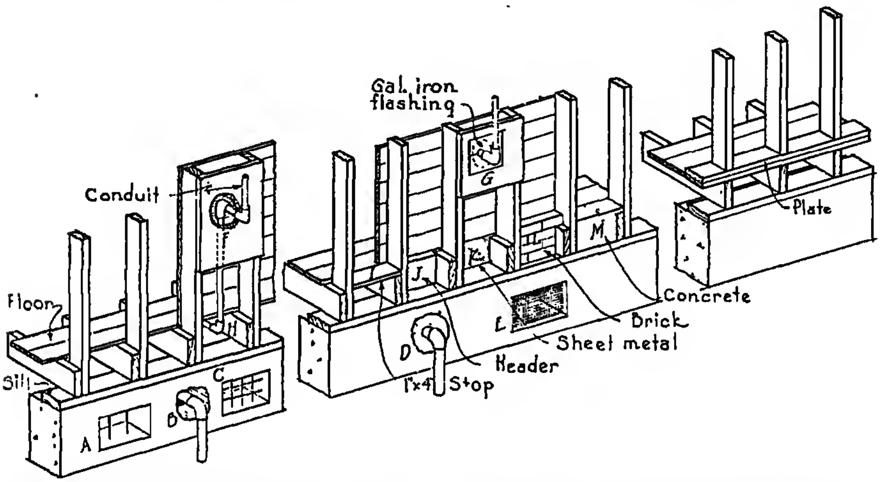


Fig. 270. Structural features of buildings in relation to exclusion of rats and mice. *Undesirable: A,* basement ventilator with wide spaces; *B,* space about entering pipe; *C,* large-mesh grill in ventilator; *F,* hole in wall around conduit; *H,* free passage from below floor into walls. *Corrective: D,* space around entrance of pipe filled with concrete; *E,* ventilator covered with hardware cloth of ⅓-inch or ¼-inch mesh; *G,* close-fitting metal flashing around entrance of conduit or pipe; *I,* stop of wood at floor level; *J,* header block between joists to close space between sill and floor; *K,* sheet-metal "header"; space between studs filled with brick, *L,* or concrete, *M.* At right, the usual "western" construction of a plate over the floor; rodents cannot pass from basement to spaces between studs and walls.

places where rats run. The dust is irritating to the feet and bellies of the rats, the animals lick it off, and poisoning results. Care must be taken not to contaminate with this poisonous dust any human food products or any feed intended for domestic animals.

In rat control, red squill is the safest poisoned bait for use by the general public, although it is not always fully effective. It is safe because other animals than rats either will not eat baits containing it, or are caused to vomit if they do. The formula for a bait containing this poison is as follows: red squill, powdered, dry, 1 part by weight; rolled oats, corn meal, peanut meal, ground meat, or minced fish (any of these separately), 9 parts by weight. With either dry or moist materials, the poison is sifted over the bait and stirred until an even mixture results. The poisoned bait is placed near rat runs or other

places showing rat activity, one teaspoonful of the mixture at each site. Squill baits also may be wrapped in 4-inch squares of soft paper to form "torpedoes" that are easy to distribute. At least 20 baits should be put down in one small building, and more in a larger structure. Baits are best put down in the late afternoon, and any that are uneaten should be removed on the second or third day following. Dead rats and uneaten baits should be completely incinerated or buried at least twenty-four inches deep in soil.

Zinc phosphide may be used with prospect of greater success in rat control, but this poison is more dangerous to handle and requires an operator with experience in its use. A suitable formula is as follows: zinc phosphide, 1 part by weight; bait, 100 parts; corn or mineral oil, 16 to 24 fluid ounces per 100 pounds of bait. The bait material should be placed in a large pan, the zinc phosphide added a little at a time, and the mixture stirred until the blackish chemical is evenly distributed. Then the oil should be warmed, poured over the bait, and the latter stirred again to obtain a uniform product. Large batches of bait may be prepared in a metal drum provided with baffles and turned by hand or power equipment. Prepared bait, if stored dry, will keep its effectiveness for some weeks.

In weighing and mixing this poison the operator should work out of doors or in a well-ventilated room, to avoid fumes from the poison; and when distributing the baits he should wear gloves or use a long-handled spoon.

Whenever rats become abundant about any citrus establishment, the management should hire a technically trained pest-control operator, or else consult a farm advisor or other agricultural agency for information about means of rat control.

## MEADOW MICE

The term "field mice" is applied to various kinds of mice that live among grasses and weeds. Of these, the meadow mice or voles (genus *Microtus*) are important to citriculture in parts of California. Meadow mice (fig. 271) are larger than common house mice, but smaller than rats.

Most species of meadow mice shear off or wear down the grass and other surface vegetation to form irregular systems of little pathways about one inch wide and two inches high; these connect with holes and tunnels which the mice make in the soil. When the grass cover is tall or dense the workings may be hidden entirely, and to search for them beneath such cover one must part the grass tops. The numbers of mice present may be inferred from the amounts of droppings and grass cuttings in the runways.

*Breeding.*—In captivity, one pair of meadow mice in a year has produced more than eighty young; these soon matured, and some bred when scarcely a month old. Under favorable natural conditions of food and cover these mice may increase quite rapidly. They sometimes reach "plague" numbers and will then strip the ground of vegetation.

*Damage.*—Meadow mice injure citrus trees by eating the bark and sometimes the wood at the base of the trunk and up to six or eight inches above the ground (fig. 272). Low, spreading branches may be cut; but mice seem not to climb them. Attacks below the soil surface are uncommon. Badly

girdled trees may die. Groves lacking mouse shelter are sometimes damaged, but more trouble results when shelter and nesting places for the mice are afforded by mulches of straw or "litter" manure around the tree bases or by accumulations of prunings and leaves under the trees. Cover crops in orchards also encourage mice. When trees are adjacent to canyons with native thickets of brush and grass, or ditches lined with grass and weeds, the mice may invade and injure the trees after this plant cover surrounding or adjacent to orchards has dried. If mulch basins are used, the mulch should be kept

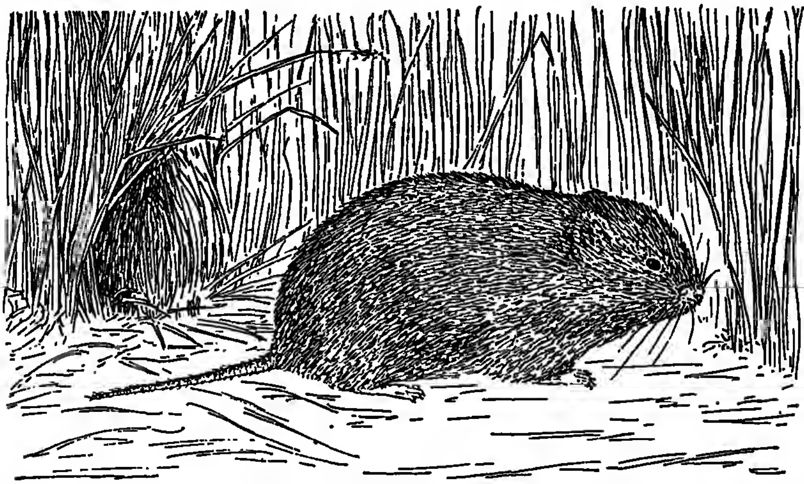

Fig. 271. The meadow mouse (*Microtus*). Distinctive features are the blunt nose, small ears, and dense soft fur of blackish brown or grayish brown color. Head-and-body 4 to 6 inches long, tail 1¾ to 2¾ inches.

from direct contact with the tree trunks and frequent inspections should be made for the presence of mice.

*Control.*—Clean cultivation of orchards and removal of cover on adjacent wild lands will lessen the chances of damage by meadow mice. There is also the practice of painting the trunks of citrus trees as high as twelve inches above the ground surface with a repellant not injurious to the bark, such as tree seal, carbolineum, or lime sulfur.

Control of meadow mice with zinc phosphide has been successful. The bait is made up of: zinc phosphide, 7 to 10 ounces; steam-crushed barley, whole oats, or oat groats, 100 pounds; mineral oil, white, 10 fluid ounces. This material is prepared in the same manner as rat poison. The poisoned bait is scattered in runways or where cuttings or mouse droppings indicate the presence of the rodents. The "government formula" for strychnine-poisoned grain for ground squirrels has been used against meadow mice with some success.

Fig. 272. Base of orange tree partly girdled by meadow mice at Citrus Experiment Station, Riverside, July, 1942. Photograph from H. J. Quayle.

## GROUND SQUIRRELS

The California ground squirrel (*Citellus beecheyi*) was formerly abundant in the southern citrus districts of California, but its numbers have been much reduced by intensive and persistent control. When its large burrows are dug in the banks of irrigation canals, they contribute to breaks and diversion of water. Burrows beneath the bases of trees may expose the roots to drying. Ground squirrels climb readily and cut off ripening fruits.

In earlier years, strychnine-coated whole barley was used extensively for control of ground squirrels. The "government formula" for this poison is as follows: barley, whole, cleaned, 16 quarts; strychnine (alkaloid, powdered), 1 ounce; bicarbonate of soda (baking soda), 1 ounce; saccharin, 1/10 ounce; thin starch paste, ¾ pint; heavy corn syrup, ¼ pint; glycerin, 1 tablespoonful. Mix the strychnine, baking soda, and saccharin together, dry; prepare starch paste with one heaping tablespoonful of dry gloss starch worked into a little cold water; then pour the paste into ¾ pint of hot water, stir, and boil until clear; add dry ingredients, then syrup and glycerin, and mix thoroughly; pour the hot mixture over the grain, and turn the grain until the kernels are evenly coated; spread out in a thin layer and leave until dry; then store in can or sack plainly labeled POISON.

Use of oat groats as bait with zinc phosphide and mineral oil (or petrolatum), prepared like the bait recommended above for meadow mice, has been successful for ground squirrel control at all seasons. Fruits poisoned with strychnine are sometimes effective. Thallium-poisoned grains and fruits have been used in recent years, but in California this poison may legally be employed only by official agencies. Gassing of squirrel burrows with carbon disulphide or methyl bromide by means of a special pump or applicator is a common practice against ground squirrels, but these gases may injure trees if the burrows extend under the roots.

Trapping will dispose of small numbers of squirrels. A modified form of the box gopher trap has been used successfully (Becker, 1940). The wooden back is replaced by two strips of metal, so that squirrels may see through the trap, the trigger is shortened and sharpened to hold baits such as whole walnuts, citrus, or melon rind, and the release on the top is reversed so that a pull on the trigger will set off the trap.

## WOOD RATS

In southern California, citrus orchards adjacent to canyons with brushy cover are sometimes damaged by "pack rats" or wood rats (*Neotoma*). The adult has soft fur, a well-haired tail, and large ears; the head-and-body is 7 to 8 inches long and the tail 6½ to 7½ inches. The rats build conical houses of sticks and debris on the ground and in trees. On citrus trees the animals cut stems to drop the fruits, but they eat only a small amount of each. Control measures include the setting of wooden rat traps near nests, employing rolled oats as bait, and inserting poisoned baits in the nest cavities by use of a long-handled spoon.

## COTTON RATS

In Texas, cotton rats (*Sigmodon*) do some damage to trees. These animals are buffy gray above and white beneath; the head-and-body is nearly 5 inches long and the thinly haired tail about 4½ inches. Cotton rats inhabit grasslands and vegetated stream bottoms, making burrows and underground nests as well as surface runways and nests somewhat like those of meadow mice. Control may be effected by the use of strychnine-coated grain (milo).

## RABBITS

The native hares or jack rabbits (*Lepus*) of the American southwest commonly injure and kill citrus trees by gnawing the bark; cottontails (*Sylvilagus*) do so occasionally. Rabbits also eat citrus fruits on the ground, or sometimes those on low branches.

Young trees surrounded by tree guards to protect against sunburn, or by cylinders of poultry netting about 24 inches tall, will usually escape damage by rabbits. The netting should be of small mesh and supported so that it nowhere touches the bark. Fencing an orchard with wire, of mesh not greater than two inches, will exclude rabbits, but is expensive. The lower edge should be buried to discourage the animals from digging beneath. Shooting is effective against small numbers of rabbits, especially in the early morning and evening, when these animals are most active.

Poisoned baits have been used to kill jack rabbits (but not cottontails, which are classed as game animals). In using such poisoning, care is required not to kill game or domestic animals. Local agricultural officials should be consulted on the method to use if this sort of control becomes necessary.

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# CHAPTER XVII

# PROTECTING THE CITRUS ORCHARD AGAINST FROST

BY

FLOYD D. YOUNG and WAYNE E. HARMAN

DAMAGE TO CROPS from frost occurs in many citrus-growing areas, with sufficient frequency and severity to justify expenditures for orchard-heating equipment, fuel, and labor to maintain adequate protection. The frost hazard varies from impaired quality of the fruit to loss of entire crops and trees. Occasionally, tree damage may result in lowered production for several seasons. Citrus trees defoliated by a severe freeze may have split bark and killed limbs, and may require five years or longer to return to normal production. During the severe freezes of 1913, 1922, and 1937, in California, hundreds of acres of citrus trees were killed outright.

In 1938 an orchard-heater survey indicated that 92,000 acres of citrus orchards in California were equipped with heaters to prevent damage from frost. This is nearly one-third of the total citrus acreage in the State. Of this protected acreage, 88 per cent is equipped with oil-burning heaters.

The purpose of orchard heating is to add heat to the lower air to replace part of the heat lost to outer space by radiation from the ground, trees, fruit, and other surfaces, and thereby to maintain a safe temperature.

## HEAT TRANSFER

In order to combat the ravages of frost efficiently, it is necessary to have some knowledge of the principles of heat transfer. In the following pages, an attempt will be made to explain as clearly and simply as possible "the reasons why" the earth's surface and the air in contact with it gain and lose heat as they do.

An interesting characteristic of heat is its tendency to flow from points of higher to points of lower temperature. There are three main methods by which this transfer may be effected, namely, conduction, convection, and radiation.

*Conduction.*—If one end of an iron bar is held in a fire, the heat is quickly communicated to the other end by being passed from molecule to molecule. In this way heat or molecular energy is transferred along the bar from the warmer to the cooler end by conduction.

Different substances transmit heat at different rates. The tile floor of a bathroom and a rug resting on it may both have the same temperature. However, the floor feels cold to the feet while the rug feels warm. The difference in sensation depends on the rate of heat conduction.

Only a short time is required for the heat to reach the cooler end of the iron bar, indicating that iron is a relatively good conductor of heat. Nearly all metals are good conductors of heat; the conductivity of water is somewhat lower; air and dry soil are both poor conductors of heat.

Soils vary in their ability to transmit heat. In general, the soil which contains the most air is the poorest conductor. In all soils, heat is conducted downward so slowly that the diurnal change of temperature penetrates no more than two or three feet.

*Convection.*—Air over a heated surface becomes warmed in the lower levels by conduction. Its volume is increased and it becomes less dense than the cooler air above it. The warmed air is forced to rise, and there is a compensating downward movement of the cooler air. In this way heat is carried aloft. These upward and downward motions of the air are known as convection. Rising air expands under diminishing pressure and its temperature falls. The heated air continues to rise until it reaches a point where its temperature is the same as that of the air surrounding it.

*Radiation.*—The two methods of heat transfer discussed above require a medium for transmission; the first a fixed, and the second a mobile medium. The third method, radiation, does not require any medium. All bodies, whatever their temperature, radiate heat, which travels in straight lines with the speed of light (about 186,000 miles per second). The character of the radiation varies with the temperature—the hotter the body, the more intense is the radiation.

The heat energy we receive from the sun comes to us as radiant waves that travel millions of miles through space so cold that no life can exist there. They warm the air only very slightly in passing through the atmosphere, but are readily converted into heat when absorbed by the earth's surface and the objects upon it.

The earth loses some of its heat to space continuously by radiation, both by day and by night. Over a long period of time the heat loss must exactly balance that received from the sun, to prevent the earth from becoming either continuously hotter or continuously colder.

During daylight hours, the earth normally gains more energy from the sun than is lost by radiation, and the surface temperature rises. After the sun sets, the radiation received from the atmosphere and clouds is usually insufficient to counteract the loss by outgoing radiation, and the temperature falls.

On a sunny day the ground surface becomes warmed and its temperature becomes higher than that of the air which overlies it. The ground then becomes a very effective source of heat for the air in contact with it, and the surface air gains heat by conduction.

At night, after the sun goes down, the ground surface cools rapidly by radiation and its temperature soon falls below that of the layer of air in contact with it. As soon as this occurs, the surface air begins to lose heat to the ground by conduction. The air tends to come to the same temperature as the surface over which it lies or moves. However, the temperature of the air lags behind that of the earth's surface. The poor conductivity of the air explains why frost sometimes forms on grass, sticks, and other objects when the air temperature is several degrees above freezing.

*Influence of slope on insolation.*—The term "insolation" is used to denote the radiation the earth receives from the sun. The slope or exposure has a

marked influence on the amount of insolation received from the sun. In the Northern Hemisphere the slopes facing south receive the strongest insolation because of the higher angle at which the sun's rays strike them. Northern slopes receive the least insolation because the sun's rays strike them at a low angle. Ground which slopes away from the sun also has the disadvantage of remaining in the shade a longer period of time. Southern slopes are more favorably situated than level ground, for even the low sun of winter warms them. Northern slopes, on the other hand, are at a greater disadvantage than level ground.

Hann (1903), in a discussion of these effects, observes that "valleys which trend east and west are more favorably situated than those which trend north and south, provided the angle of slope of the enclosing mountain sides is the same, because the north and south valleys are in the shade longer than the east and west valleys."

In hilly sections, the marked differences of exposure and slope produce considerable variations in the warming of the soil within short distances and at similar elevations above sea level. However, these variations tend to disappear at night in areas where the steepness of the slope is sufficient for air drainage to be effective.

Using Gessler's values for the amounts of solar radiation received on slopes of various inclination and exposure throughout the year for latitude 45° north, Geiger (1927) constructed the curves which are reproduced in figure 273. The amount of solar radiation is given as a product of duration of sunshine and the varying intensity of the insolation. The unit of insolation is the "equatorial hour," which is the amount of insolation received by a horizontal surface at the equator in one hour when the declination of the sun is zero. The four diagrams refer to different inclinations of the ground.

Theoretically, a slope facing east receives during the day the same amount of insolation as a slope similar in every respect but inclining to the west. Hence, the abscissa values are the same from north to south through either east or west. There are two scales of ordinates; the left indicates the months with increasing declination of the sun, and the right, those with decreasing declination.

It is evident from figure 273 that in summer the various exposures do not differ greatly in the amount of insolation received unless the slope is quite steep, but in winter and spring the southern slopes are far more favorably situated than those of northern exposure. A slope of 45° facing north receives no direct insolation between the middle of September and late March.

*Influence of soil and vegetation on minimum temperatures.*—Land surfaces exposed to sunshine either reflect, transmit, or absorb the solar radiation which gets through the atmosphere. The amount that is reflected varies greatly with the condition and color of the surface. According to Blair (1937), "if the land is covered with grass or trees, or is black, cultivated soil, the reflection is very small, less than 5 per cent. A bare hard sandy soil may reflect 20 per cent, and freshly fallen snow, 70 per cent of the incident radiation."

In general, the absorption of solar radiation varies roughly with the visual

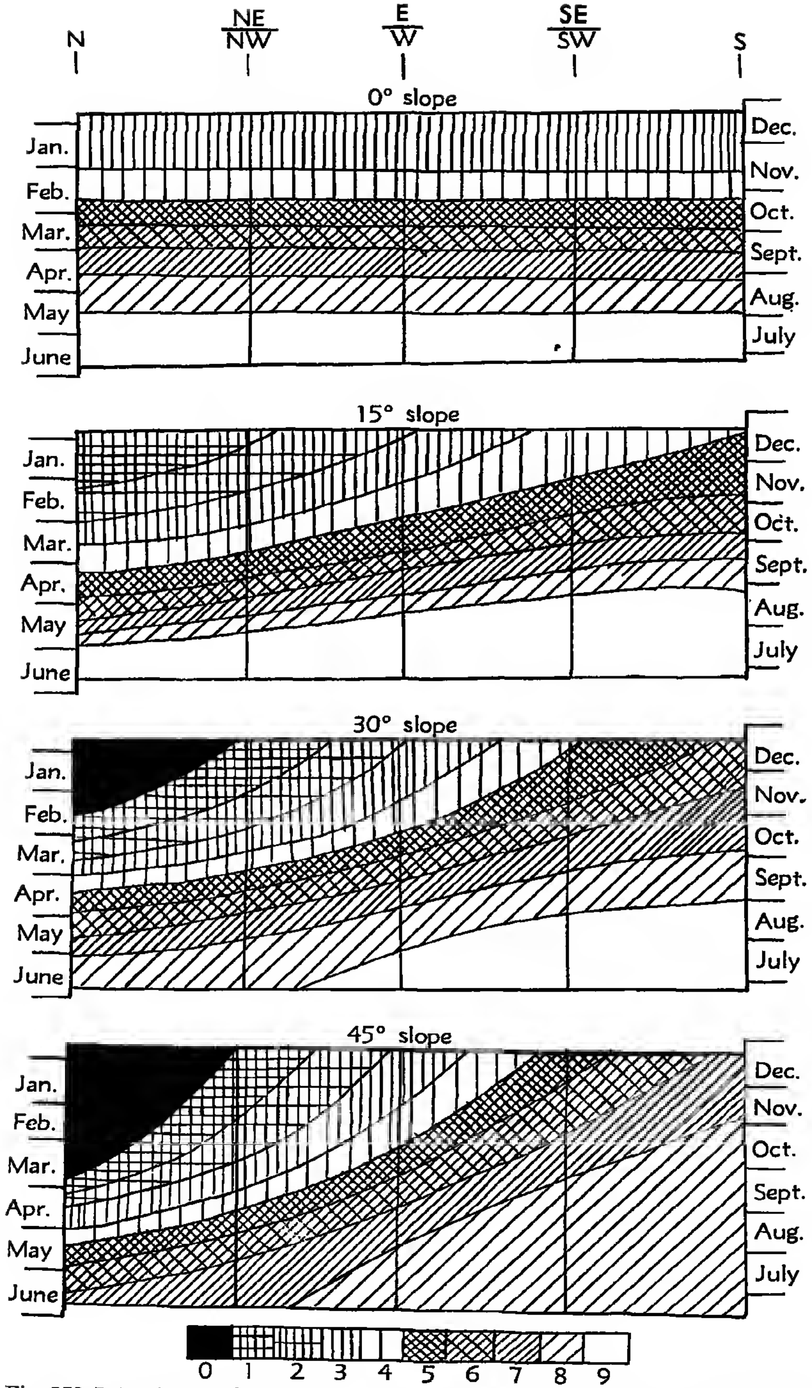


Fig. 273. Intensity of solar radiation on slopes of various inclination and exposures.

darkness of the surface. Nearly all soils are relatively good absorbers. However, good absorbers are also good radiators, and the land surface that heats rapidly by day cools rapidly by night.

Dry soils, as remarked above, are poor conductors because they contain relatively large amounts of air. For this reason the rise in temperature is confined to a thin surface layer of the dry soil and very little heat is conducted downward. This is an important consideration since much of the heat conducted into the ground in the daytime returns to the ground surface at night by conduction and helps to prevent a greater temperature fall. The combined effect of good absorption and poor conduction is to cause the surface soil to heat rapidly when the sun shines upon it and to cool rapidly at night when the sky is clear. In general, the diurnal variation of temperature will be greatest over sandy soils and least over clay soils when skies are clear.

The frequency of radiation frosts is much greater when the soil is dry than when the soil over the countryside is somewhat moist. Running irrigation water in furrows in citrus groves offers only a slight degree of protection against frost damage; however, large-scale flooding of orchards is more effective. This method is not recommended because of the adverse effect on the trees if the soil is kept flooded over a period of several days.

Investigations have been made (Young, 1925) to determine the effect of cover crops on orchard temperatures. An orchard in cover crop was divided into two five-acre plots, and sheltered thermometers at elevations of five feet and of ten inches were placed near the center of each plot. After a series of frosty nights, a temperature relationship was established between the two plots. Temperatures averaged 0.1° F. lower at the 5-foot elevation and 0.2° F. lower at the 10-inch elevation in the west plot than in the east plot. The cover crop in the east plot was then plowed under and the temperature records covering twenty-four frosty nights were obtained. After applying the average temperature difference between the two plots before the cover crop was removed, it was found that the cover crop lowered the minimum temperature an average of 0.5° F. at the 5-foot elevation and 1.3° F. at the 10-inch elevation above the ground. However, it was found that the cover crop restricted the free movement of air, and on windy nights temperatures as much at 11° lower occurred for short periods of time in the plot with the cover crop. As soon as the wind ceased, the temperature in the clean-cultivated area fell rapidly until it was almost as low as that in the cover-crop area.

On nights when the temperature barely reaches the danger point in clean-cultivated citrus orchards, the lower temperature in orchards with cover crops may cause the loss of some fruit within three feet of the ground, but the fruit in the upper part of the tree is not likely to be affected.

*Effect of water vapor on radiation.*—Investigations have shown that the loss of heat from the earth's surface on a clear, calm night varies with the amount of water vapor in the overlying air as well as with its temperature.

All the long-wave radiation from the surface of the earth does not escape to space. Much of it is absorbed by the water vapor in the lower layers of air. It is then reradiated both upward and downward, the amount emitted in

either direction being dependent on the mean temperature of the atmospheric column.

Since water vapor is practically transparent to the short-wave solar radiation and absorbs most of the long-wave radiation from the earth, it acts like the glass in a greenhouse. It lets through practically all incoming radiation from the sun, but hinders outgoing radiation from the earth. This blanketing effect is important in checking the fall in temperature on a clear, calm night. It has been calculated that the average temperature of the earth would be at least 50° to 60° F. lower if all water vapor were absent from the atmosphere.

The water vapor in the atmosphere varies greatly in concentration from time to time and from one location to another. The dew point is an index of the amount of moisture in the air, a high dew point indicating moist air and a low dew point relatively dry air.

*The dew point.*—The dew point is a temperature—the temperature at which dew or frost begins to condense out of the atmosphere as the temperature falls on a clear, calm night. When we say the dew point is 45° F., we mean that as the temperature falls in the course of the night, when it reaches 45 degrees, dew will begin to form on vegetation and other objects exposed to a clear sky. If the dew point is 28° F., no dew will form, but frost will begin to appear on exposed objects when the temperature reaches 28°.

Occasionally we have low temperatures with exceptionally low dew points, and when this occurs we may have heavy damage to vegetation without any deposit of either dew or frost. In other words, suppose the dew point is 10°, and the temperature falls to 22 degrees above zero in the course of the night. Since the temperature did not fall to within twelve degrees of the dew point, there would be no dew and no frost. but a great deal of damage to crops would result. Frosts of this type are sometimes known as "black frosts."

The dew point is an indication of the amount of moisture in the atmosphere: the higher the dew point, the greater the amount of water vapor in the air. The atmosphere is sometimes extremely dry in southern California, as is indicated by the dew-point readings below zero that have been recorded. We are sometimes asked how the dew point can be below zero. The answer is that since the temperature can be below zero, the dew point, also being a temperature, can also be below zero. When below-zero dew-point readings occur, it means that the temperature would have to drop below zero before frost would form.

A knowledge of the dew point for his particular district is valuable to the citrus grower in several ways. On nights when the dew point is high, say above 35° F., the temperature fall is usually slow and steady, with slight, if any, fluctuations. When the dew point is low, on the other hand, say 25° F. or lower, there are likely to be fluctuations up and down. When the dew point is exceptionally low, the temperature may even fall as much as eight degrees in fifteen minutes. When the dew-point temperature is 40° F. or higher, the rate of temperature fall usually lessens materially after the dew point is reached, and sometimes the temperature remains almost stationary for an hour or more at the dew point.

It has been found that oranges and lemons start to freeze earlier when they are wet with dew than when they are perfectly dry, and the grower knows he can take more chances in his protective operations when the dew point is so low that there will be no deposit of moisture on his trees.

## AIR DRAINAGE

When sloping ground is cooled by radiation to a clear sky at night, a thin layer of air in contact with it is cooled until it becomes denser than the air at the same level in the free atmosphere. It is impossible for the cooled air on the slope to accumulate much, because of its increased density. It moves downslope toward the valley and is replaced by warmer air overlying the

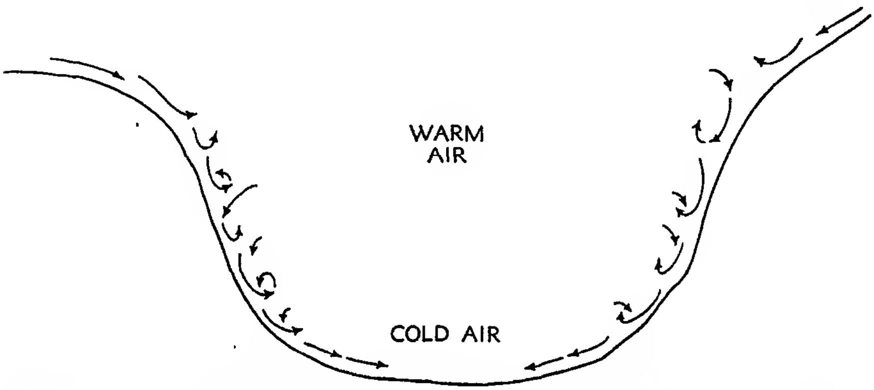


Fig. 274. Cross section of a valley showing the numerous small-scale wind circulations which develop along the slopes on a clear, calm night.

valley. Such circulations are best developed on clear, calm nights when other meteorological factors do not disturb them.

Where there is a steep hillside, the descending air is compressed and warmed in accordance with a law governing the behavior of gases. This warming effect results in a separation of the moving air from the cooling surface in such a way that numerous small-scale circulations develop along the steeper slopes. It is doubtful whether any of the air chilled by contact with the cold valley walls in the higher elevations of the air-shed areas ever reaches the lower levels of the valley floors. There is a mistaken belief among many orchardists that when the mountains are covered with snow there is danger of severe frost in the valleys because of the cold winds which blow down off the snow. Under these conditions the hazard of frost lies in the low daytime temperatures and atmospheric conditions that caused the snow.

Along gradual slopes the radiational cooling that takes place as the air slowly descends to lower levels is usually sufficient to compensate for the dynamic effect of warming, and the cold surface air drains down the slope in much the same manner as water (fig. 274).

A shallow lake of cold air gathers in each depression, and gradually be-

comes deeper as the chilled air is discharged from the slopes. If the valley floor has a gentle slope, the cold air gathers to become a moving stream rather than a quiet lake or pool. The frost hazard is comparatively greater in those lowlands which receive the gravity inflow of cold air from an air shed of large area.

*Temperature inversion.*—When the cold, heavy air has settled into the lowlands with a relatively large body of warmer air remaining aloft, the condition is described as one of "temperature inversion." The amount of temperature inversion varies from night to night, depending on previous weather conditions. Sometimes the inversion is of only a few degrees, following a cold, windy day when the normal rise in daytime temperatures has been reduced or prevented. Large inversions occur on clear, calm nights following warm, sunshiny days if the air is dry enough to permit rapid loss of heat from the ground by radiation.

A study has been made of nocturnal temperature inversions and the influence of slope on minimum temperatures along a slope in the Pomona Valley, California. Temperature stations were placed at frequent intervals, as shown in figure 275. The average minimum temperature for forty-five clear nights is given, with mean isotherms sketched in to give an outline of the body of warm air overlying the valley. In the absence of upper air temperatures the position of these isotherms is approximate. However, they are drawn in accordance with well-known principles of air stratification in the early morning and are believed to be fairly accurate. Note that the temperature increases most rapidly with elevation in the lowest levels of the inversion. Temperatures along the hillside are only slightly lower than those of the free air at the same level. The temperatures in parentheses represent particular nights when the temperature inversion was very weak and minimum temperatures on the slopes were only slightly higher than on the valley floor.

Temperature stations were also placed along a uniform gradual slope (fig. 276). In this and similar investigations, it has been found that the slope must exceed 150 feet per mile (approximately 3½ per cent slope) before cold air will drain away at a rate of speed great enough to affect minimum temperatures significantly along the slope.

Within reasonable limits, excluding high plateaus or mountains, elevation above sea level, or above the valley floor, does not by itself have any influence on the relative degree of frost hazard in near-by locations. A depression high up on a hillside, into which the cold air can drain faster than it moves out, may be fully as cold as a similar depression at the foot of the slope on a clear, calm night. Flat or well-rounded summits of hills are almost always colder than steep slopes below on such nights.

Night winds are also of great importance in determining temperature differences between hillsides and valley floor on clear nights. Ideal conditions for air drainage are found only when there is no general air movement in the district. Even a light wind will interfere materially by mixing the relatively warm air above or away from the slopes with the thin stratum of surface air which has been cooled through contact with the ground. A moderate

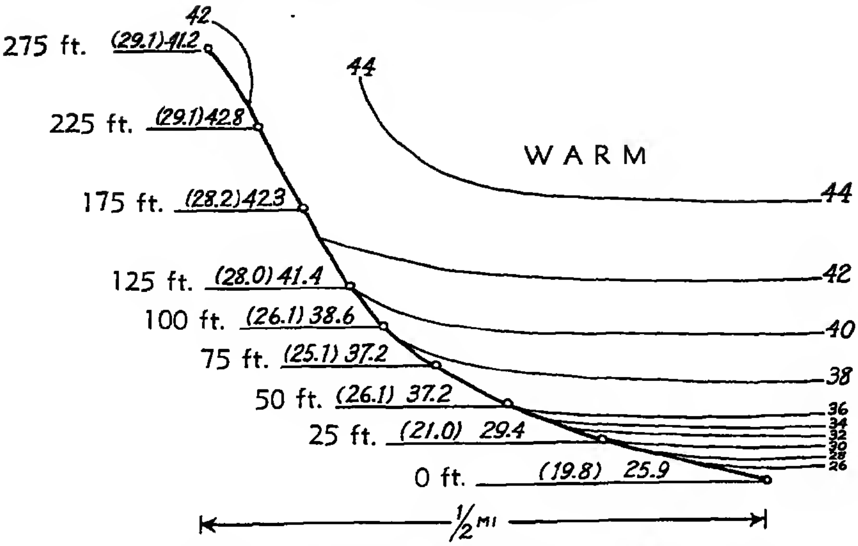


Fig. 275. Average minimum temperatures for 45 clear nights during the winter of 1918–19 in the Pomona Valley. Survey made along the steep slope shown at the right in profile of figure 276. Figures in parentheses represent a night when there was a weak temperature inversion.

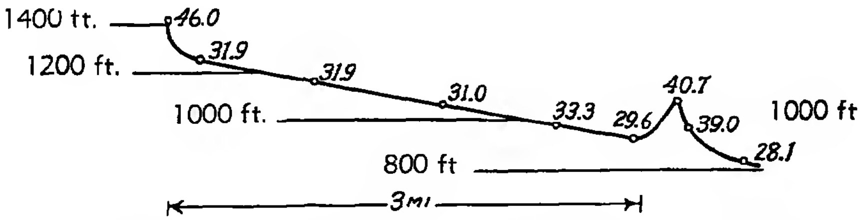


Fig. 276. Average minimum temperatures for 29 clear nights along a uniform gradual slope.

wind may prevent stratification entirely, both on the slopes and on the valley floor, and there may then be little or no difference in temperature between hill and valley. With a pronounced temperature inversion, winds of more than four miles per hour cause the surface temperature to rise as a result of mixing the warm air at moderate elevations with the colder air below.

## WHEN TO EXPECT FROST*

Frosts or freezes may follow almost any type of local weather, and predictions based on local indications alone are likely to prove disappointing. However, there are a few local indications that may prove of some value.

The weather of the United States is largely governed by the movement of,

* The practical considerations of orchard heating, in the following discussion, are summarized from Young (1940).

and interaction between, great moving masses of air which originate in different regions and have different characteristics of temperature, moisture and wind. They may be divided broadly into two main types: polar, or cold, originating in the north, and tropical, or warm, originating in southerly latitudes. Each air mass carries with it its own particular type of weather. The most changeable weather, accompanied by cloudiness, wind, and often by rain or snow, is normally found near the boundaries between two air masses, of differing characteristics, called "fronts." A boundary at which warm, moist air is overrunning relatively cold air is known as a "warm front." A front at which cold air is pushing under, and lifting, a warm air mass is known as a "cold front." Speaking very generally, the passage of a warm front is accompanied by a blanket of heavy low clouds and more or less continuous precipitation, whereas the passage of a cold front is characterized by intermittent precipitation, followed by broken cloudiness and, later, clearing skies.

Practically all freezes and a large proportion of local frosts follow the passage of a cold front and the subsequent influx of polar air. Cold rain or sleet is followed by intermittent showers or thunderstorms, then clearing skies and falling humidity. At times, however, frost does not immediately follow the cold-front passage because of wind conditions. Relatively cold polar air masses usually move southward in the westerly part of a cyclone, or low-pressure area, and in the eastern part of an anticyclone or high-pressure area.

Although moisture in the ground after a rain tends to prevent warming of the ground during the day, it also tends to prevent a large fall in temperature during the night. When the dew point is reached, the latent heat given up checks the rate of cooling, and when the abundant surface ground moisture freezes, the liberated heat also aids in checking the rate of fall in temperature.

By the second night after the rain the surface of the ground has usually dried out considerably, the dew point is likely to be lower, and there is more danger of a damaging frost. Before the third night the day temperature usually has risen high enough to make a heavy local frost unlikely, although there are exceptions to this rule. In California, heavy frosts sometimes occur after a strong influx of polar air, without any local indications of the passage of a cold front. Low night temperatures occur immediately after the cessation of strong, dry, north to east winds.

Large bodies of water exert a modifying influence on the climate of near-by localities to the leeward, and such localities are less liable to damage by frost. A light wind blowing from a large body of water is generally more or less laden with water vapor, which retards the rate of surface cooling; and as the temperature of the water is usually well above freezing, that of the air passing from it to the land is often high enough to prevent the formation of frost.

Rivers often give up a large amount of moisture to the surface air, so that when the temperature falls to the dew point a surface fog forms which covers a part or all of the lower land in the valley, absorbing and returning radia-

tion and preventing a further fall in temperature. In valleys near the ocean, fog sometimes drifts in from the water, toward morning, and prevents a damaging frost. On nights with ground fog, the hillsides are almost always colder than the lowlands unless the fog extends high enough to cover both hillsides and valley floor.

## DAMAGING TEMPERATURES

So many factors must be taken into consideration in determining whether a given temperature will cause damage to fruits, buds, or blossoms, that a correct judgment is not always easy. The length of time the low temperature persists, the vigor of the tree, and the weather preceding the frost, all bear upon the amount of damage that will be done.

Other conditions being the same, the fruit or blossoms on a weak, undernourished tree will show more injury than those on a vigorous tree after both have been subjected to the same low temperature.

*Frost injury to citrus fruits.*—It is difficult to name definite critical temperatures for citrus. The length of time the low temperature persists, the vigor of the tree, the weather preceding the frost, the maturity of the fruit, and the rate at which the temperature has been falling, all affect the amount of frost damage to oranges, lemons, and grapefruit that will result from a given temperature. The size of the fruit is also important, since small fruits cool more rapidly than large ones.

The thick, pithy rind of the orange is a poor conductor of heat, and because of the protection it affords, the temperature of the interior of the fruit falls more slowly than the temperature of the outer air. When the air temperature is falling rapidly, the interior of the fruit may be as much as 7° F. warmer than the air surrounding it, and the fall of temperature inside the fruit may lag from an hour to an hour and a half behind that of the air temperature.

After the fruit begins to freeze, its temperature will remain at, or very near, the freezing point of the orange until it is frozen solid, no matter how low the temperature in the orchard may fall (fig. 277). The temperature at which freezing of the fruit begins is slightly different in different oranges of the same variety, even on the same tree. In experimental work done by the Weather Bureau, the freezing points of ripe navel oranges varied from 27° to 28° F. Half-ripe Washington navels began to freeze at fruit temperatures of from 28° to 29°, and green navels at from 28.5° to 29.5°. The fruit itself must reach the temperature given above before freezing will begin; the air temperature may be, and usually is, several degrees lower.

Citrus fruits on the outside of the tree cool more rapidly than those sheltered by foliage, and on a clear, calm, frosty night the most exposed oranges on a tree may be as much as three degrees colder than those within the tree. It often happens that a moderately low temperature will freeze only the exposed part of the rind of the orange, giving it a water-soaked appearance, usually called the "water mark." If the orange is colored, the part of the rind that has been frozen turns a very light yellow on the day following the frost. Such oranges are called "shiners."

The problem of determining what temperatures will damage citrus fruits

is further complicated by a phenomenon known as "undercooling," by which is meant the cooling of the fruit below its freezing point without the formation of ice. Navel oranges have been known to cool as much as 3° F. below their freezing point before freezing began. Undoubtedly, oranges are often undercooled several degrees, and afterward the temperature rises again, without the formation of ice and without damage to the fruit. The first formation of ice crystals in an undercooled fruit is accompanied by a rise of the fruit temperature to approximately its freezing point. The amount of undercooling

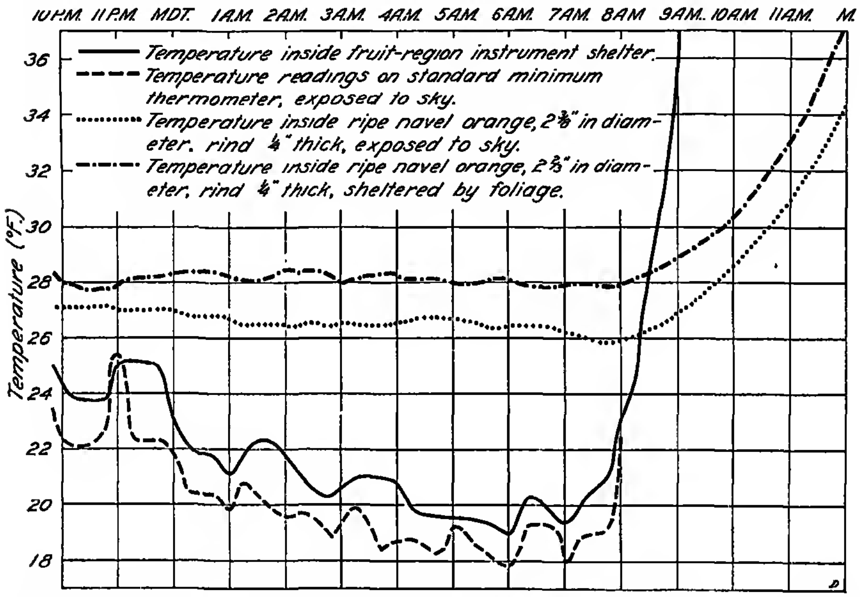


Fig. 277. Temperatures inside two ripe navel oranges, one exposed to the sky and the other sheltered by foliage; also readings of two standard minimum thermometers, one inside a standard instrument shelter and the other exposed to the sky. (From Young, 1940.)

NOTE.—The fruit in this orchard was a total loss, owing to the low temperatures on this one night. Both the sheltered and the exposed oranges had already begun to freeze when the observations were begun. These records illustrate in a striking manner the fact that the temperature inside the orange after freezing begins will not fall much below the freezing point of the orange until it is frozen solid, no matter how low the temperature of the air in the orchard may fall. This is a point that must be kept in mind when fruit temperatures are used to determine when protection is necessary.

which the fruit will undergo on a given night cannot be determined in advance, although there appears to be less undercooling when the fruit is covered with ice than when it is perfectly dry. However, until further information regarding undercooling of fruit on the tree under natural conditions is obtained, it will not be practicable to take this factor into consideration in determining when to light the heaters.

In general, the nights on which heating will be necessary to protect oranges and grapefruit may be divided into two classes. The first class will include

those on which a local frost occurs, when the cooling is due principally to loss of heat by radiation. Such nights usually follow warm afternoons. The temperature drops rapidly but does not reach 27° F. until 2 or 3 o'clock in the morning. The fruit temperature is likely to be several degrees above the air temperature on such nights, and so long as the air temperature continues to fall steadily, lighting of heaters to protect ripe, or nearly ripe, navel oranges or grapefruit can be delayed until the sheltered thermometer registers 26° F. Under similar conditions, heating for the protection of green navels or Valencias should start at 27°. In any case, it is best to keep the temperature about 28° F. after heating starts.

The second class of nights on which heating is necessary includes the "freeze" nights. The preceding afternoons are usually cold and windy, often with a cloudy sky. The temperature falls below the danger point early in the night and remains there until sunrise; or the temperature may fall only slightly below the freezing point of the fruit early in the night and remain practically stationary until morning. On such nights it is necessary to light the heaters before the temperature has fallen much below the freezing point of the fruit. Lighting of heaters for nearly ripe navels should be started when the sheltered thermometer reaches 27° F. Green navels or Valencias should be heated when the temperature has been stationary at 28° for 2 hours or when the temperature is falling slowly and has reached 27.5°.

It is even more difficult to advise concerning temperatures at which heaters should be lighted for the protection of lemons. Lemon trees carry buds, blossoms, and fruit in all stages of development at the time protection is necessary. Open blossoms, buds about to open, and small green fruits one-fourth inch or less in diameter, are most susceptible to damage, sometimes showing slight injury following temperatures of 30° F. for 30 minutes. However, temperatures as low as 29° for 30 minutes are often endured at these stages without damage. Tree-ripe fruits are damaged at only slightly lower temperatures than the small green fruits. Green fruits more than one-half inch in diameter, and small, tightly closed buds are relatively hardy. Green fruits three-fourths inch in diameter or larger have been known to withstand temperatures below 29° F. for 7½ hours, and below 26° for 2½ hours, with a minimum temperature of 24.2°, without injury. Growers who attempt to save only the larger green fruits usually will be safe in allowing the sheltered thermometer to fall to 27° for 30 minutes or less, maintaining the temperature in the orchard at 28° or higher after the heaters are lighted.

Green lemons which are frozen when about one-fourth inch in diameter sometimes remain on the tree and grow to maturity, but make only rough, thick-skinned, juiceless fruits of no commercial value (fig. 278).

Fruit temperatures at which freezing begins in Marsh grapefruit vary between 28.5° F. and 29°. Under the most adverse conditions, with slow temperature fall and a deposit of ice on the outside of the fruit, mature fruit on the outside of the tree will show some damage after a temperature of 26° has held for 30 minutes. Under more favorable conditions, with low humidity, dry fruit, and a rapid fall in temperature, damage will not begin until the

temperature has remained at 24° for 30 minutes. After orchard heaters have been lighted, air temperatures in the orchard should not be allowed to fall below 28°.

Badly frozen oranges and lemons usually show positive evidence of damage within a few days after the low temperatures occur, the length of time being dependent on temperature and weather conditions which follow. The warmer and drier the days following the damage, the more rapidly the fruit breaks down. Eventually the fruit loses most of its juice. Valencia oranges, if only

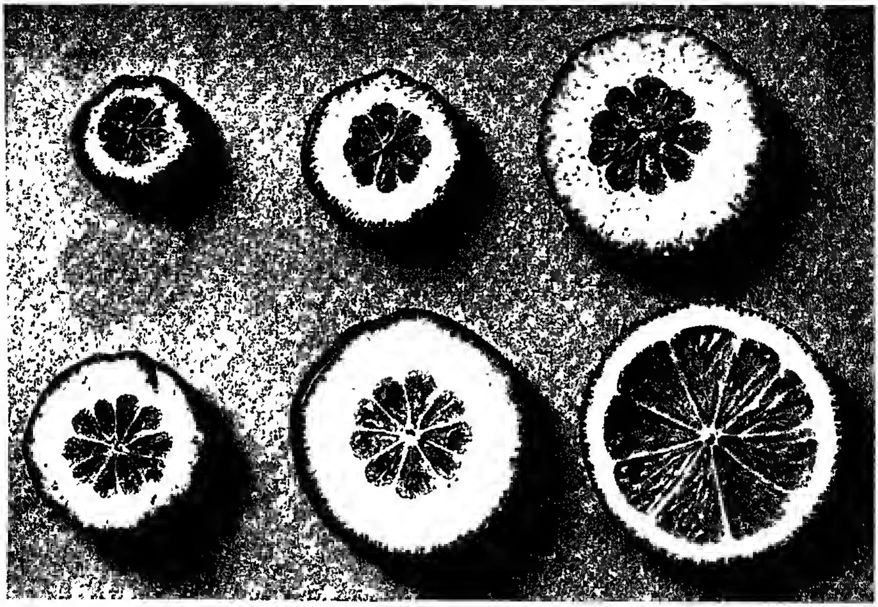

Fig. 278. Eureka lemons of varying sizes which were damaged by frost when very small, showing abnormal development of rind. These fruits were picked 11 months after the frost occurred. The lemon in the lower right-hand corner of the photograph is a normal fruit of packing size, 2 inches in diameter. (From Young, 1940.)

slightly damaged, may show almost complete recovery at harvest time, but navel oranges seldom show material improvement.

Frozen oranges tend to hang on the trees during a dry winter but are likely to drop soon after a freeze that occurs in a winter with plentiful rainfall.

A water-soaked appearance between the segments marks the only evidence of damage to Marsh grapefruit immediately after the ice inside the fruit has melted. Often, the only indication of damage a few days after the fruit is frozen consists of a markedly lighter color in the parts of the fruit in which ice has formed. Much badly damaged fruit has remained on the trees 2 to 3 months after it has been frozen, without drying out, finally fermenting and breaking down at a time of high day temperatures.

Resistance to damage from low temperature varies in individual citrus blossoms, owing to differences in stage of development, position in the tree, and inherent vigor. For example, a few orange blossoms will usually be damaged when orchard temperatures are allowed to drop slightly below 30° F., but when there is a profusion of bloom a temperature of 25° F. for 30 minutes will still leave enough blossoms undamaged to set about 25 per cent of a full crop. A temperature of 28° for 30 minutes will ordinarily cause little or no reduction in the size of the final crop of oranges and grapefruit if there is a heavy bloom.

*Frost injury to citrus trees.*—The amount of injury to citrus trees at the time of a freeze will depend a good deal on the weather preceding the freeze. If the soil and air have been warm and the trees have had plenty of moisture, they will be in a succulent growing condition, and a freeze will cause the maximum amount of damage. If the weather has been cold and cloudy, so that the trees are semidormant, damage by a freeze will be considerably less. Trees that have been weakened by lack of proper care are damaged by higher temperatures than those that have been kept strong and vigorous. Mature navel orange trees in southern California, in rather poor condition, were about 75 per cent defoliated by a temperature below 20° F. for 6 hours, with a minimum temperature of 18° F., in the freeze of 1922. Another navel orange grove near by, in good condition, was about 10 per cent defoliated by a minimum temperature of 19.8° on the same night. On the morning of January 3, 1924, a mature California orange grove endured a temperature of 16° for 1½ hours, and 13 hours below 27°, with only about 10 per cent defoliation. The trees were almost dormant, whereas in 1922 they had been in growing condition all winter.

A mature California lemon grove was entirely defoliated in the freeze of 1922 by a minimum temperature of 20° F., and the bark on the trunks of ten-year-old trees was split on a night when the minimum temperature fell to 19°. During the winter of 1924–25 several temperature stations were maintained by the Weather Bureau in a twenty-year-old lemon grove. In the lower part of the grove, where the lowest temperature was 22.6°, the trees were completely defoliated; on slightly higher ground, where the lowest temperature was 24°, they were about 50 per cent defoliated; and on still higher ground, where the lowest temperature was 26.5° F., only the tender new growth was killed. In the San Joaquin and Sacramento valleys in California the trees become more nearly dormant under average winter conditions than in southern California and consequently will endure without damage somewhat lower temperatures. (See also effect of fertilization of trees on frost damage, in chap. vii above.)

## TEMPERATURE MEASUREMENT

It is well known that a thermometer exposed to the sky on a clear, calm night loses heat by radiation to the sky and shows a temperature lower than the actual temperature of the air surrounding it. In other words, the exposed thermometer merely indicates its own temperature. This may be 1°, 2°, or

even 3° lower than the temperature of the air surrounding the thermometer, depending on the amount of moisture in the air and the type of thermometer used. Generally speaking, dark-colored substances radiate heat more rapidly than lighter-colored; or those with a high polish.

It is often suggested that because the orchard trees are not sheltered from the sky, unsheltered thermometers should be used to determine the temperatures which damage the fruit. However, there is no reason to believe that an exposed thermometer will indicate correctly the temperature of the buds, blossoms, or fruits, especially since a dark green fruit will radiate heat to a clear sky more rapidly than a white blossom.

The lower part of a tree is usually more or less screened from the sky by adjoining trees, and blossoms or fruit in the interior of a tree are almost completely screened by the leaves, branches, and fruit above. The most exposed part, that which is cooled most by radiation to the sky, is the top, and the cooling is almost always more than offset by the difference in air temperature between the top and the base of the tree, owing to temperature inversion.

The object in sheltering a thermometer is to eliminate, so far as possible, the effects of loss of heat by radiation, and to obtain, as nearly as possible, the actual temperature of the air. As a matter of fact, the air inside an instrument shelter is usually slightly colder than that outside the shelter on a clear, calm night, because the shelter itself is cooled by radiation to the sky. The only temperature observations which are at all comparable one with another are those made with sheltered thermometers.

It has been stated that a relatively large amount of heat is required to change liquid water to water vapor. Evaporation is going on at all times, even when the temperature is below freezing. When a thermometer bulb is covered with a film of water, ice, or frost, the evaporation that is taking place absorbs heat from the thermometer and cools it below the temperature of the air. The amount of cooling depends on the amont of moisture in the air and the rate at which *the air* is moving past the thermometer.

A satisfactory shelter must screen the thermometer from the sky and from direct sunlight and must also prevent the deposit of moisture on it from any source. Free circulation of air is also an important requirement for a satisfactory exposure. It is essential, therefore, that a thermometer shelter allow as free a circulation of air as is possible without sacrificing the elements of protection from sunlight and liquid or frozen moisture. Standard Weather Bureau shelters (fig. 279) have double roofs to prevent undue warming of the inside air by the sun's rays, and the bottoms and sides are well ventilated.

In exposing all thermometers used for determining orchard temperatures, the foregoing principles should be borne in mind. Whenever possible, standard instrument shelters should be used. If this is not practicable, a fairly satisfactory thermometer shelter can be constructed from an apple box attached to a post, firmly anchored to prevent vibration, the bottom and front of the box being open (fig. 280). All shelters should be faced squarely toward the north, in order to prevent direct sunlight from striking the ther-

mometers during the day, and should be painted white, to reduce cooling by radiation at night. Thermometers should be 4½ feet above the ground.

In reading a thermometer on a cold night, care should be taken not to breathe directly on it, and an electric flash light should always be used in making readings. When matches, candles, or lighting torches are used to illuminate the thermometer scale, the temperature may be raised a degree or

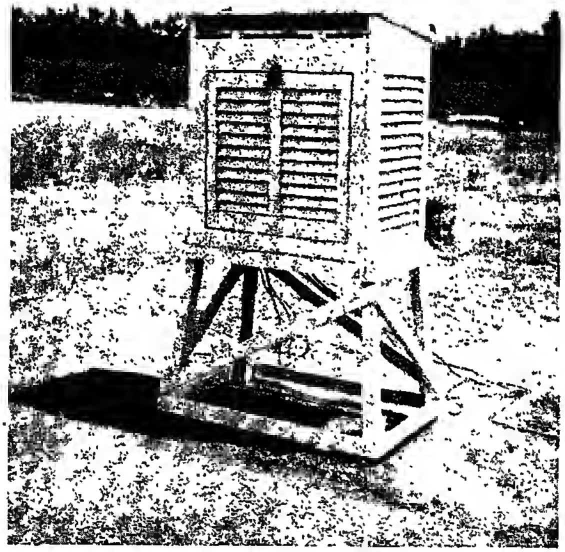

Fig. 279. Standard Weather Bureau thermometer shelter. (Photograph by Maurice Donnelly.)

more before the reading can be made; this may result in loss of fruit occasioned by failure to light the heaters in time.

Every orchardist who has frost-fighting equipment should have at least two accurate, dependable thermometers, preferably of the type which register the minimum temperature. In larger orchards there should be one thermometer to each five acres. Thermometers should be checked for accuracy at least once each year, and those found to be in error more than one degree near the freezing point should be discarded. Inaccurate instruments should be marked so that the correction can be applied when making a reading. Information on types of thermometers developed especially for orchard-heating work may be obtained by writing to the Weather Bureau.

In the protection of large orchards a thermograph will be found helpful. A satisfactory type for this purpose can be obtained for approximately $100.

## PROTECTION AGAINST FROST

Since a crop which represents the results of the labor and care of an entire season may be destroyed by frost in a single night, various methods of protection against frost have been practiced for centuries in different parts of the world.

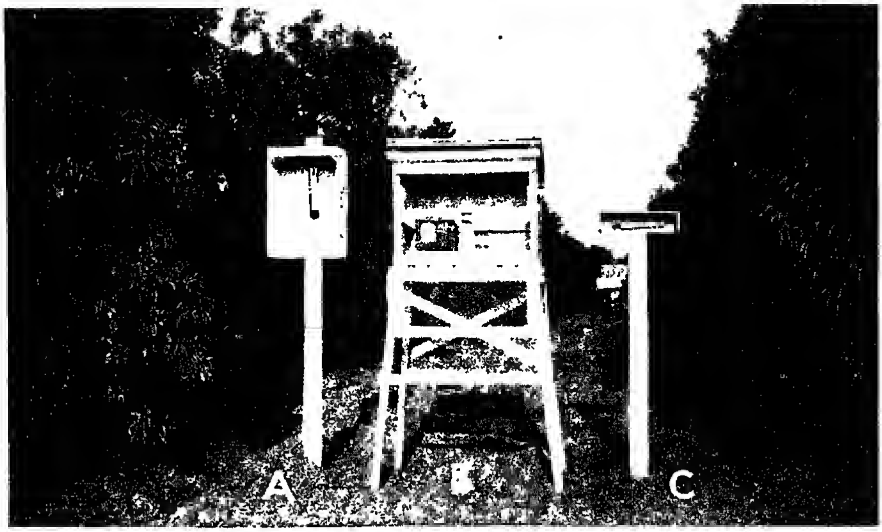


Fig. 280. *A*, rough type of shelter for a vertical thermometer, which may be constructed from an apple box attached to a post and firmly anchored to prevent vibration, the bottom and front of the box being open; *B*, Weather Bureau fruit-region instrument shelter, showing exposure of thermometers and thermograph, suitable for use only in fall, winter, and spring, recommended for sheltering thermometers and thermographs used in orchard-heating work; *C*, rough type of shelter for horizontal minimum thermometer, made with two thin boards about 9 or 10 inches wide and 16 or 18 inches long, placed at right angles to each other, one constituting the back of the shelter and the other providing a cover for the thermometer. The shelter is secured to a post about 5 feet high, and the top board is hinged so that it can be thrown back when the thermometer is being set. (From Young, 1940.)

Frost-protection methods in the United States utilize three general principles: (1) conserving heat, (2) adding heat, and (3) mixing or stirring the air.

### CONSERVING HEAT

Cooling of the ground at night is due principally to net loss of heat by radiation to the sky. If radiation loss can be reduced sufficiently, the temperature will not fall to the danger point. This may be accomplished in varying degree by covering the ground or plants with various materials.

*Smoke screens.*—Smudge fires of damp straw or manure have been used to create a blanket over the area to be protected, the object being to conserve

heat rather than add it to the air. Such a method may be of some slight benefit when the air is calm and is already almost saturated with moisture. However, heavy frosts usually occur when the humidity is fairly low, and there is almost always at least a slow drift of air. In a relatively dry atmosphere, any moisture thrown off by damp smudge fires will be rapidly lost by circulation and diffusion into the air above and surrounding it, and the effect in conserving heat will be very small. Furthermore, if an effective blanket of moisture could be spread over an orchard, a slight breeze would carry it steadily away, to be replaced with cold outside air.

Experiments have shown definitely that chemical smoke screens such as those used in military operations not only afford practically no protection against frost damage, but also are considerably more expensive than orchard heating.

Great quantities of orchard-heater smoke in the air after a cold night, which screen crops from strong sunlight throughout much of the day, have appeared to reduce the amount of low temperature damage materially. Whether this is due to slower thawing of frozen vegetation or directly to shielding from strong sunlight is not known. A bank of clouds forming in the eastern part of the sky before sunrise on a frosty night appears to have the same effect in reducing the amount of damage.

*Covering.*—In parts of Alabama and Florida, mounds of earth are piled around small citrus trees in the fall, covering the trunk to above the bud union. A severe freeze may kill all that part of the tree which is above the earth covering, but the trunk is not injured, and a new top can be grown in much less time than a new tree.

In California, citrus trees under six years of age are sometimes protected by wrapping the trunks with cornstalks or tules. The covering material should be two to three inches thick, and bound tightly to the trunk, reaching from the ground to the head of the tree. Any space left between the base of the covering and the ground should be covered by heaping soil around it. The trees should be wrapped in the fall, before frost danger threatens, and the wrappings should be removed as soon as the danger period has passed in the spring. When the wrapping material is removed, the tree trunk should be given a heavy coat of whitewash to prevent sunburn.

## ADDING HEAT

The second principle of frost protection relates to the addition of heat to the lower air to replace that lost by radiation and conduction. This is generally accomplished by lighting a large number of small fires throughout the area to be protected.

Persons unfamiliar with temperature conditions in the lower air on frosty nights sometimes speak of the fallacy of attempting to "warm up all out of doors." It is well known that warm air is less dense, and therefore lighter, than cold air. This fact is exemplified in many ways in everyday life; the hot gases from a stove or furnace rising through a flue and the lifting power of the old hot-air balloons are good illustrations. Warmed air continues to rise

and cool until it has the same temperature as the air surrounding it. At first thought, it might be supposed that the air warmed by the fires in orchards or fields would pass upward to an appreciable altitude and be replaced by cold air from outside the heated area so rapidly that the effect on the temperature in the heated area would be very slight. However, this is not so.

*Factors which influence orchard heating.*—On a clear, calm night there is a relatively thin layer of cold air near the ground, with an increase in temperature up to a height of 300 to 800 feet. This condition, known as temperature inversion, makes effective orchard heating possible. The hot gases leave the heaters at a high temperature, but rapidly mix with the surrounding colder air so that the temperature of the whole mass is not very high. This air mass which has been slightly heated does not rise far before it is sur-

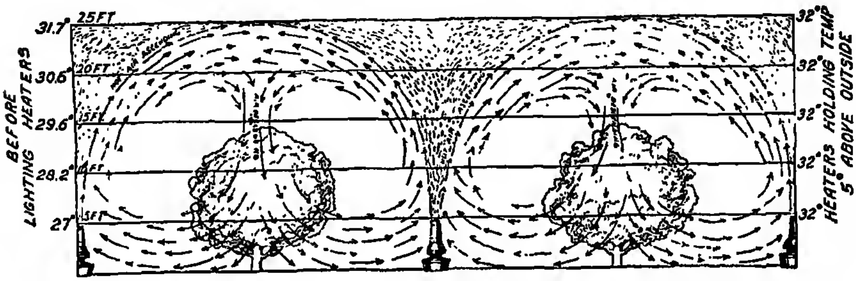


Fig. 281. Cross section of a row of orchard trees and orchard heaters, illustrating the manner in which temperature inversion makes effective orchard heating possible. This diagram represents air currents and temperature conditions in the orchard on a typical calm, frosty night a few minutes after the heaters had been lighted. Later the shaded area will completely fill the space below the 25-foot level. Here, the thickness of the stratum of air heated is 25 feet, and the temperature rise obtained at an elevation of 5 feet above the ground is 5° F. (From Young, 1940.)

rounded by air of the same temperature as itself. When this occurs, the upward movement is checked. In other words, the warmer air above the orchard acts as a roof which stops the ascent of the heated air (fig. 281).

To illustrate, let us assume that the air 5 feet above the ground in an orchard has a temperature of 22° F., and that the temperature of the air 40 feet above is 30°. Let us assume also that, after the heaters have been lighted, the temperature of the mass of heated gases rising from the heaters, mixed with the air of 22° temperature in the orchard, is 30°. This mixture, being 8° warmer than the surrounding air, will rise until it reaches a point 40 feet above the ground. Here it comes to a stop, because it is no longer warmer than the surrounding air, which also has a temperature of 30°. The heaters continue to supply quantities of the mixture of heated gases and air at a temperature of 30°, which stop rising at lower and lower elevations until the temperature of the air down to the ground has been raised to 30°. When this has been accomplished, the air temperature in the orchard has been raised 8°, and the temperature inversion has been destroyed; that is, there is no longer any difference in air temperature between the 5-foot and 40-foot levels. Thus,

the heat from the burning heaters has been expended in raising the temperature of the air within 40 feet of the ground.

It is plain that the degree of temperature inversion near the ground determines the depth of the layer of air that must be warmed to obtain a definite increase in temperature at the ground. If there is a rapid increase in temperature with increase in elevation, the surface temperature can be raised several degrees more than when the rate of increase is slight, the amount of fuel consumed being the same.

The amount of this temperature inversion varies greatly from night to night, and in different localities. It is mainly determined by the amount of fall in temperature from afternoon to early morning. If the afternoon temperature is high, and it falls to freezing on the following morning, the inversion is likely to be great, and orchard heating unusually effective. The most difficult nights, when protection is necessary, are those following cold afternoons, when the inversion in temperature is slight.

A large number of small fires is more efficient than a small number of large fires, especially in localities where the temperature inversion is relatively slight. The heated gases leave the large fires at a high temperature and tend to rise some distance above the ground, whereas the gases from a larger number of small fires are mixed with the surrounding cooler air until the temperature of the whole mass near the surface is raised slightly, although remaining still relatively low.

Another and probably the most important factor in protection by heating is the amount of air movement near the ground. When the air is calm, that part of it which is warmed by the heaters remains over the fired area, and the maximum results in raising the surface temperature are obtained. When the air is in motion, even though it be moving only a few miles per hour, the heat is steadily carried away, and a greater quantity of fuel must be consumed in order to obtain the same effect on the surface temperature.

Because of this air drift, which is found on nearly all frosty nights, a large orchard can be protected with less fuel consumption per unit area than a small one, unless heating is practiced generally in the neighborhood. In general, the fuel consumption per acre on an isolated 10-acre orchard will be about double that on a 150-acre orchard in obtaining a given rise in temperature on the same night.

The protection of the border rows of trees in an orchard with an extra line of heaters is important. If no border row of heaters is provided, the air drift will carry the heat from the first two or three rows of fires on the windward side into the orchard, leaving the outside rows practically unprotected. To protect border trees, a row of heaters 10 feet apart should be placed 20 feet to the windward of the outside row. Orchard-heater smoke has very little influence, and the effect of smudge fires of damp straw or manure on the temperature is practically negligible. The belief held by many fruit growers that the smoke "holds the heat down" is without basis.

*Direct radiation from heaters.*—All orchard heaters radiate part of the heat produced in the combustion of the fuel. The higher the temperature at

which the heater operates, the greater will be the proportion of the total heat produced that is in the form of radiation.

Part of the heat radiated by an orchard heater is lost directly to the sky, without appreciable effect on the temperature of the air or of the plants. Radiant heat travels in straight lines and is completely absorbed or reflected by fruit, leaves, or ground, which may intercept it. Some indirect warming of the air takes place through contact with surfaces which have been warmed by radiation from the heater. During the progress of cold waves, or freezes, when temperatures below the danger point are accompanied by wind and lack of temperature inversion, radiation from the heaters to the trees may be of primary importance in preventing damage. In the protection of low-growing crops, such as potatoes, strawberries, or cranberries, the radiated heat plays an important part in maintaining a safe temperature.

*Fuels for orchard heaters.*—The primary consideration in orchard heating is to supply heat enough to offset the natural cooling through radiation of heat to the sky, and to raise above the danger point the temperature of the cold air drifting into the orchard. Theoretically, it does not matter particularly what fuel is burned, provided enough heat units are supplied to maintain a safe temperature and the heat is properly distributed throughout the orchard. Many different grades of oil have been used in orchard heating, from the heavy crude oil as it comes from the wells to refuse cylinder oil drained from automobile motors. Coal, coal briquets, wood, oil-saturated wood shavings, tree prunings, baled straw, carbon briquets (a by-product of the manufacture of illuminating gas from crude oil), a mixture of coal dust, asphaltum, sawdust, and niter, and even discarded automobile tires, have been used as orchard-heater fuels. The use of many of these fuels is extremely limited, owing to the small supply available. Others are eliminated from serious consideration because of their cost. Next to availability and cost, the amount of labor involved in protecting an orchard successfully has probably had more influence than any other one factor in limiting the number of orchard-heater fuels for general use. At present, oil is an overwhelming favorite as a fuel for frost protection. Carbon briquets and coal briquets are used to a limited degree in the citrus districts of California.

Wood has never been much used for orchard heating outside of Florida, principally because of the great amount of labor involved. Pine wood heavily impregnated with pitch was formerly rather widely used for orchard heating in Florida, but it is becoming increasingly more expensive and difficult to obtain.

Experience has shown that if the proper grade of oil is used, this fuel involves the least amount of labor. On the other hand, briquets have certain advantages over oil for protecting small acreages. Briquets are easily handled and stored, and eliminate the necessity of having storage and distributing tanks. Disadvantages of briquets as compared with oil are the following: After they have been lighted, it is difficult or impossible to extinguish them in case the temperature rises. The lowest temperature usually occurs about sunrise; hence the heaters must be delivering their maximum amount of

heat at that time, making a loss of fuel almost unavoidable. The heaters must be refueled at frequent intervals in order to maintain a safe and fairly even temperature in the orchard. When coal briquets are burned, the ashes must be shaken from the heaters frequently to prevent the smothering of the fire, particularly if it is necessary to continue the firing over a long period. Briquet heaters depreciate more rapidly than oil heaters because of their higher metal temperatures and the lack of a protective coating of oil. However, if briquet heaters are properly handled and a sufficient number to the acre are used, they are as dependable as the oil heaters in maintaining a safe temperature.

Carbon briquets make an extremely hot fire and leave very little ash, but the supply of this fuel is limited. They are more difficult to light than coal briquets, and have caused some difficulty because they have burned out heater grates. They burn with little smoke after the first few minutes, but sometimes give off sulfur fumes in quantities large enough to be objectionable.

Petroleum coke, a residue composed of almost pure carbon, obtained in gasoline "cracking" plants, is an excellent fuel for use in solid-fuel heaters, particularly when briqueted. It creates a hot fire and leaves very little ash.

Coal coke is unsatisfactory as an orchard-heater fuel. It is difficult to light and the fire is almost smothered by ashes soon after it is lighted.

Electric power as a source of heat for frost protection is entirely impracticable because of the large amount of electricity required to protect even a small orchard.

Lard-pail and other types of open oil heaters, as well as heaters of the distilling type, will burn a good grade of diesel oil without difficulty, but pipe-line heaters and some drip heaters require a lighter oil with a difference as wide as possible between evaporation temperature and cracking temperature. The pour point, which is the temperature at which the oil becomes so thick that it will no longer flow, must be well below any temperature likely to be experienced in the field. An excess of water in the oil will cause the heater to boil over or explode, and an excessive amount of asphaltum will fill it with a hard, sticky mass, difficult to remove. In purchasing oil for orchard heating, the grower should specify the lowest asphaltum content obtainable, and should never accept oil containing more than 1 per cent asphaltum. If it is not possible to obtain definite information about the asphaltum content, a sample of the oil should be burned in an orchard heater; the proper type of oil should leave only a small amount of dry, cindery residue in the bottom of the heater after it has been burned dry five times. Almost all the larger oil corporations can supply an excellent orchard-heater oil, from 28° to 40° B., containing practically no water or asphaltum. The lighter oils burn somewhat faster and contain slightly fewer heat units per gallon, but the difference is too small to be of much consequence. Pipe-line heaters and most types of drip heaters require a better grade of oil, commonly known as kerosene distillate, than the open-pan and distilling type (stack heaters).

Sulfur content of all orchard-heater oils should be kept to a minimum and should be below 1 per cent, to avoid excessive corrosion of the heaters.

*Fuel storage.*—In order to handle orchard heating successfully, it is necessary to have fuel enough within reach to last through the longest cold spell likely to occur. Too often, the crop has been protected successfully through several cold nights at considerable expense, only to be lost on the last night of a freeze because of lack of fuel. Where orchard heating is practiced by many growers in a community, it is a good plan to buy and store large quantities of fuel oil on a coöperative basis, as is done in southern California. The heaters in orchards that are in the immediate vicinity of the community storage tanks can be filled by hauling oil directly from these tanks, but individually owned storage tanks should be installed in every fired orchard more than a half mile from the community supply.

The amount of oil stored at the orchard should equal at least three times the capacity of all the heaters. If possible, orchard storage tanks should be arranged so that they can be filled and emptied by gravity. If it is not possible to do this, they should be elevated, so that the wagon tanks can be filled by gravity. It is better to pump oil into the tanks than to pump it out, since the failure of a pump used to lift oil from an underground tank may cause the loss of a crop. In recent years, corrugated galvanized sheet-iron tanks have been installed almost exclusively for orchard storage in southern California. The use of corrugated iron makes it possible to use a lighter-weight iron without reducing the strength of the tank.

Concrete storage tanks should be heavily reinforced with steel and should be coated with oil-proofing material to prevent leaks.

In the citrus districts of California the erection of tanks for oil storage on a coöperative basis is usually handled by the local packing-house unit of a coöperative-marketing organization, the cost being borne collectively by all the growers affiliated with the local unit, whether they practice orchard heating or not. Growers who do not protect their groves feel that they may desire to equip them later, or that the stabilizing of the operations of their organization is of sufficient importance to warrant their coöperation.

In some districts in California, however, the cost of these community tanks is borne entirely by the growers who protect their orchards, and it is then necessary to form a separate nonprofit coöperative corporation under the laws of the State. The par value of each share of stock is dependent on the amount of storage per share which the owner is allowed in the community tank. A share of stock representing 500 gallons of storage space usually costs from $8 to $10. Outside of the annual cost of carrying on the work of the association, which is usually very small, the grower's initial investment in his stock is his last capital investment. The association acts only as agent and does no financing. In order to insure the use of the proper type of oil in the orchard-heating operations, the board of directors reserves the right to determine the grade and quality of the oil to be stored. Shares of stock may be sold, with the directors' approval, so that a grower may receive full value for his stock if he sells his grove.

Provision should always be made for cleaning oil-storage tanks, especially if the heaters are emptied into the tanks at the end of the season. The soot

and sludge remaining in the heaters after they have been burned several times gathers in the lower part of the storage tanks, and, if not removed at frequent intervals, soon materially reduces the effective storage capacity. Care should be taken to keep storage-tank covers watertight to prevent leakage of water into the oil.

Briquets or other solid fuels for orchard heating are usually carried in stock by local dealers, but it is well for the fruitgrower to keep on his own property fuel enough for three nights of firing. Reserve fuel is often piled in the open, but it will be found much more satisfactory to store it in bins under cover.

*Distribution of heaters.*—For the best distribution of heat throughout an orchard it is better to have the heaters placed in every row, if that is possible, instead of concentrating them in alternate rows. This makes for a more general intermixing of the warmed air with the surrounding cold air, and also allows heat radiated directly from the heaters to reach nearly every part of the tree. The concentration of heaters in alternate rows will give satisfactory protection, on nights with radiation frosts, to orchards on slopes where there is a consistent air drift from the same direction, provided the heater lines are placed at right angles to the line of drift. During freezes, however, when the air is uniformly cold and wind may come from several different directions on a cold night, there is usually damage in the rows without heaters, even when there is no damage in the rows in which the heaters are concentrated.

The heated air from a fired orchard often drifts through the adjoining parts of neighboring orchards not fired, and may afford them even more protection than it gives to the fired orchard itself.

*Filling heaters.*—Some growers who protect 5 acres or less with oil, fill the heaters from metal drums of about 50-gallon capacity. A wagon tank is usually more satisfactory and is almost a necessity where more than 5 acres are protected. Three men with a wagon tank can fill heaters rapidly, one man driving and two men filling. The oil is drawn into 5-gallon buckets with lip and spout, and two to four rows of heaters are filled on each trip. Some growers use heavy rubber hose for filling the heaters directly from the wagon tank. Two lines of hose are attached to the tank outlet, and one or two rows of heaters on each side of the tank wagon are filled on each trip. This method eliminates carrying oil from the tank to the heaters. Great care should be taken not to injure the tree roots by spilling oil in the orchard. Stack heaters should be filled to about one inch below the top of the bowl. A greater amount of fuel makes lighting difficult.

A great many methods of filling briquet heaters are in use. Probably the most efficient and the one requiring the least labor is to load the fuel on light wagons for hauling through the orchard. A large funnel, its mouth slightly smaller in diameter than the top of the heater, is placed therein, and the fuel charge is poured from a shovel built to hold the correct quantity of fuel. In this way the fuel is lifted down from the wagon instead of being lifted up from the ground. Reserve fuel for refueling at night is kept in boxes placed beside each heater. Reserve fuel should never be stored on the

ground, as weeds or other plants may grow over it and make it difficult to find at night. The reserve-fuel box should be placed not nearer than eighteen inches from the heater, to prevent its taking fire.

*Lighting heaters.*—All types of heaters are lighted by use of a special lighting torch burning a mixture of gasoline and kerosene in equal proportions. The torch is made in the shape of an ordinary oil can, but larger, with a capacity of from one to two gallons. The diameter of the spout is large enough to allow a small stream of the lighting fluid to pass through when the torch is inverted. At the end of the spout is an asbestos wick, which carries the flame. As the lighting fluid passes the wick, it is ignited, and a stream of burning liquid is poured into the heater.

If these torches are correctly designed and constructed and reasonable precautions are taken in handling them, no danger should attend their use. A small-mesh metal screen is soldered over the base of the spout to prevent the ignition of gases in the fuel reservoir. If the screen is properly attached, slight explosions of the gases in the spout may occur without danger since the flame will not pass through the screen. The screen should be examined at the beginning of each frost season to make sure that it is intact and firmly soldered to the rim of the spout. The diameter of the spout should be as small as possible and still allow an adequate flow of lighting fluid. A large spout may contain a quantity of explosive gas large enough to blow out the screen and ignite the gas in the reservoir, causing a serious explosion. In the torches most recently devised, the air to replace the lighting fluid poured out of the spout is taken into the reservoir through a very small pipe soldered into the back part of the top of the reservoir and extending the full length of the torch handle. In torches earlier designed, the air passed back through the spout, interfering with the flow of lighting fluid and tending to carry the flame back into the spout, thus increasing the danger of explosion.

Care should be taken to see that the torch spout is screwed down firmly, so that there will be no leakage at the connection. It is advisable to have about an inch of wicking extending beyond the end of the spout, as there is a tendency for the fire to jump back into the spout when a short wick is used. When torches are carried through the orchard, the spout should be uppermost. If the torch is carried in an inverted position, the flame from the wick heats the spout to a high temperature, which increases the danger of explosion. It has been found through long experience that a mixture of equal portions of gasoline and kerosene makes the best lighting fluid. When pure gasoline is used, the danger of explosion is greatly increased, and the fluid lacks body to carry the flame to the surface of the oil. The lighting mixture should be made up fresh each frost season. Growers have been known to try carrying over their supply of lighting fluid through the summer months, with unfortunate results: during the hot days of summer, most of the gasoline evaporated, leaving only the kerosene; when the time came for lighting the heaters, the torches refused to burn and much of the crop was lost before gasoline could be obtained and a new lot of lighting fluid prepared. If the lighting mixture is made up in large quantities and left standing in drums,

as is often done on large orchards, the liquid should be thoroughly mixed by stirring or shaking before it is drawn off into the torches.

New heaters are usually difficult to light the first time. To light new lard-pail heaters, the lighting fluid should be poured in a ring around the inside rim, so that the flame will burn on the inside walls of the heater. After they have once been burned dry, the soot adhering to the sides will act as a wick, and the heaters can be lighted rapidly.

The larger heaters, with stacks and drafts, should be wicked before being lighted the first time. Any one of a number of materials can be used for wicking. Wisps of excelsior, small rolls of newspaper, or short lengths of hemp rope are the materials most commonly used. The wicking material should be loosely inserted in the draft hole of the heater, care being taken not to choke the draft. After the heaters have been burned for an hour or more, they can be lighted easily and rapidly without wicks.

Most types of high-stack heaters must be burned at a high rate when first lighted, until the oil and the heater have been thoroughly warmed, or they may fail to burn. The usual practice is to open the drafts wide for lighting, regulating the rate of burning about five minutes later. The drafts should be adjusted from time to time during the night, as the oil gets lower in the reservoir, in order to maintain a clean flame and to prevent overheating the stack, which results in an unduly high depreciation.

In placing stack heaters in the orchard, the draft openings should be faced uniformly in one direction for easier lighting and regulating.

One lighting torch should be kept on hand for each five acres, and one or more additional for emergencies.

In citrus orchards the initial lighting of the stack oil heaters includes nearly always half or all the heaters in the grove, the temperature increase being regulated through the manipulation of the drafts.

Briquet heaters are lighted with a torch similar to that used for lighting oil heaters but having a larger lighting-fluid capacity. Paraffin-soaked balls of tow, dried peach pits, carbon or wood-shavings briquets soaked in oil, and oil-soaked wood shavings, are some of the materials used, in addition to kindling wood, for lighting the briquet heaters in the citrus districts.

Under competent supervision, high school students and students in the higher grades in grammar school provide an excellent and dependable supply of labor for lighting heaters. One man should be able to light heaters on a minimum of five acres.

*Oil heaters.*—Citrus groves should be equipped with heaters having a capacity of at least nine gallons of oil. A great many types of large-capacity oil heaters with stacks have been developed, but only a few are in general use. All the improved types use either the "down-draft," the "drip-feed," or the "gas-generating" principle. In the down-draft heaters, air is admitted through the top of the oil reservoir, causing combustion to take place on the surface of the oil and raising the temperature sufficiently to change some of the oil to gas. The hot gas is then burned as it passes upward through the stack. Air to complete the combustion is admitted through perforations

in the stack near its base. In one type of short-stack heater, combustion is improved by means of heating the air before it passes through the perforations into the stack, by admitting it through a space between the stack and an outer metal shell. In the drip-feed heater, the oil is fed from a separate reservoir through a small pipe to the burner, which is set at the base of the stack.

Oil is fed under pressure to gas-generating heaters through underground pipes leading from a central reservoir. After the heater is lighted, the flame plays on a chamber through which the oil passes, changing the oil to gas, which is burned as it passes from an orifice. Gas-generating and most drip-feed heaters require a better type of oil than open-container or stack heaters.

The normal rate of burning of the larger heaters is one-half gallon of oil per hour, but their consumption can be more than doubled by increasing the draft opening, or, for the drip-feed and gas-generating heaters, by increasing the flow of oil through the feed pipes. The gas-generating heaters burn with less smoke than any other type, but the better types of drip-feed and high-stack heaters are satisfactory when properly regulated and kept clean. All these more expensive types of heaters in fairly general use will protect crops satisfactorily in most of the established fruitgrowing districts.

The lard-pail or other open oil heater should never be used for the protection of citrus crops, because of the soot deposited on the fruit. For adequate protection, citrus groves should be equipped with fifty of the more nearly smokeless heaters to the acre. Stack and drip-feed heaters should have a minimum fuel capacity of nine gallons.

The use of small oil heaters which burn slowly, set directly under the trees, is impracticable. It has not been possible to distribute the heat uniformly through the trees, and when the heaters are burned under citrus trees there is danger of serious tree injury if they burn too high.

*Care of oil heaters.*—The amount of attention given to storage and care of oil heaters varies greatly in different parts of the country. In parts of California where the annual rainfall is light, many fruitgrowers leave the heaters in the orchards during the entire year, setting them up close to the trunks of the trees after the danger of frost is past. Trees are sometimes injured, or even killed, when oil from leaky heaters penetrates the soil around the roots.

The owners of many of the larger orchards using the stack heaters believe it pays well to give them a thorough overhauling every two years. They are disassembled and hauled to a central point, and after the old coat of paint and heater oil have been burned off, care being taken not to damage the metal by overheating, the bowls are brushed thoroughly with a steel brush to remove rust and dirt, and are examined for leaks. They are then heated on an iron grating over a fire, and a good grade of stack paint is applied hot. Some growers coat the bottom of the heater bowl by floating it on a reservoir of very hot asphaltum, using stack paint to cover the rest of the heater. The mixture of soot and asphaltum in the bottom of the heater at the end of the firing season makes excellent fuel for heating the bowls.

*Solid-fuel heaters.*—Orchard heaters burning solid fuels should be set in citrus orchards in the proportion of 100 to 125 to the acre. Briquet heaters are loaded in a great many different ways in different sections. The most common method of fueling in the deciduous-fruit districts is to place 17 briquets in the bottom of the heater, add a handful of dry pine kindling, split fine, and then 9 more briquets above the kindling. A slightly heavier fuel charge is used in the citrus districts, usually about 30 briquets to the heater.

Coal-briquet heaters deliver their maximum amount of heat about 20 minutes after being lighted, and after 2 to 2½ hours of burning the intensity of the fire is considerably reduced. Starting with the original charge of 26 briquets, the heater should be refueled with a charge of 8, not later than the second hour of burning. A refuel charge of 8 briquets should be added at the end of each additional hour of operation, as long as the heaters are burned. If the initial refueling is delayed until the end of the third hour, the new charge is likely to smoulder and smoke for some time before it begins to burn properly. The addition of cold, damp fuel to a fire that has burned down to a bed of glowing lumps actually reduces the amount of heat given off by the heater for some time afterward. At the time of each refueling, the top of the heater should be grasped with gloved hands and the ash cleared from the fire by shaking. An extra refueling is often necessary just before sunrise, to take care of the sudden drop in temperature that usually occurs at that time. Usually a new charge of from 4 to 6 briquets will supply the additional amount of heat necessary to offset this temperature fall.

Several different types of briquet heaters are in use in the citrus districts, in some of which the fuel is ignited at the top, the fire working slowly downward. This gives a longer burning period and a somewhat more even heat.

Carbon briquets burn more slowly and longer than the coal briquets and maintain a more even temperature in the orchard. They are usually lighted from the top, since the grates are likely to be damaged when the fuel is lighted at the base. When solid-fuel heaters burning carbon briquets or petroleum coke, and equipped with draft openings at the base, are used, care should be taken to avoid opening the drafts too wide, since both heaters and grates may be badly damaged by too hot a fire.

*Smokiness.*—The University of California Experiment Station has made an exhaustive study of the general problem of smokiness of oil-burning orchard heaters. This research was conducted by the Division of Agricultural Engineering, in coöperation with the Citrus Experiment Station at Riverside.

Tests have been made to determine the smokiness of various types of heaters in general use. These tests showed that there is a great difference in the smoke output of the various types of heaters, that the different characteristics of the various commercial fuel oils in use have no important influence on the smokiness of different heaters, and that the proper regulation and frequent cleaning of many of the simple, inexpensive heaters will permit operation within the permissible smoke-tolerance limits. As a result of these studies, heater manufacturers have improved the design of heaters and heater stacks and the smokiness of oil-burning heaters has thus been reduced.

*Factors affecting smokiness.*—The smokiness of heaters is influenced by the following factors:[1]

1. Burning rate: Curves of smokiness vs. burning rate (fig. 282) show definitely that most heaters when clean have a more or less fixed range of burning rates within which the smoke output is at a minimum for that particular type of heater. Within this range the smokiness is not greatly affected by the burning rate, whereas at rates above this range the smokiness increases

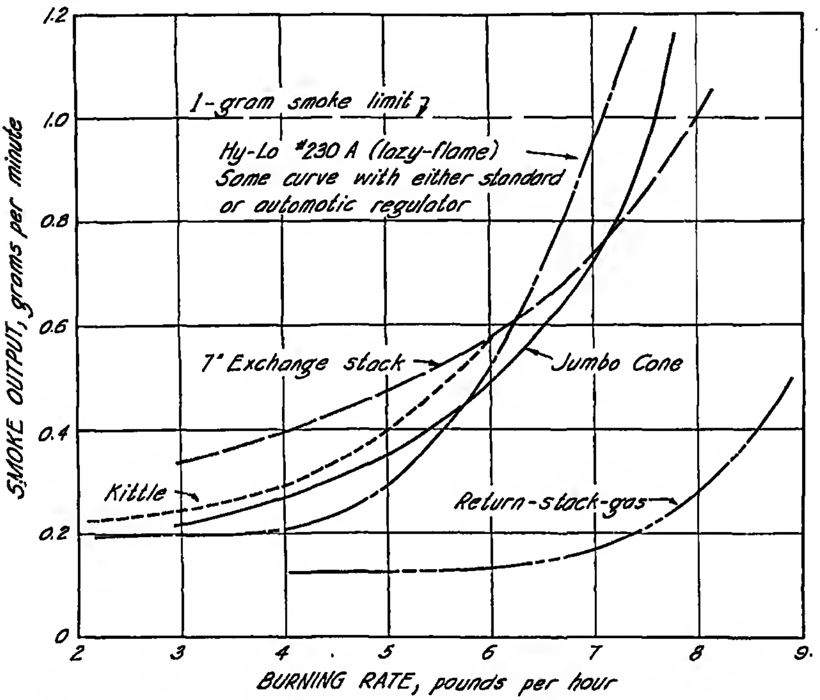


Fig. 282. Relation of smokiness to burning rate for clean heaters (laboratory tests). (From Kepner, 1940.)

rapidly with increase in burning rate. For some heaters this range is narrow, but for the better heaters it is relatively wide. The grower should determine the range of burning rates over which his heaters will burn with the least smoke and should regulate his heaters accordingly. If the smoke output is to be kept within acceptable limits, the heaters must not be operated at excessive burning rates. Judging from curves of smokiness vs. burning rate for the stack-type heaters studied in the field tests (fig. 282), these heaters all have relatively low smoke outputs over fairly wide ranges of burning rates *when they are clean*. Curves are not shown for the Fugit and petroleum-coke

[1] The discussion of most of the important factors causing smokiness of heaters is adopted from Kepner (1940).

heaters, since their smoke outputs are relatively low for all practical operating rates.

2. Soot accumulation: All oil-burning orchard heaters accumulate soot while burning, some rather rapidly and others at a lower rate. Soot accumulations, particularly in the stacks, contribute directly to heater smokiness. For this reason, stacks and covers should be cleaned regularly. How often the cleanings should be done will depend upon the type of heater and the rate of burning. It may be noted that, in general, high burning rates contribute to rapid soot accumulations, whereas lower rates of burning result in slower soot accumulations.

The simple cylindrical stacks are readily cleaned by running a wire brush through them, but the stack should first be removed in order to avoid pushing the soot deposits into the bowl. Combustion chambers should be taken apart if thorough cleaning requires it. While the stacks are off, the covers should be cleaned by reaching through the stack opening with a scoop or ladle by means of which the soot may be scraped off, caught, and removed from the bowl. Down-draft tubes may need cleaning occasionally, particularly if filling of the heaters is done through some opening in the cover other than the one above the draft tube. Smokiness is increased if the slots in the down-draft tube become clogged with soot.

3. Air leakage around covers and regulators: In the handling of heaters between heating seasons, covers, regulators, and stacks are apt to become bent and otherwise damaged so that they do not fit tightly. It is much easier to keep the covers tight-fitting on round bowls than on square bowls. Air leakage into the bowl increases soot accumulations and smokiness, besides making it difficult to control the burning rates accurately. Air leakage at the base of the stack, especially with lazy-flame heaters, causes a marked increase in smokiness. Careful handling of heaters, and the discarding or repairing of damaged bowls, covers, and stacks, help to overcome these problems. Heaters left in the field from season to season should give less trouble from this cause than those emptied and hauled out of the orchard every year. The more times a cover is removed, even though not damaged, the greater the tendency to air leakage.

4. Type of oil: Smokiness is not much affected by the usual variations in characteristics of clean oils that are within the range of fuels satisfactory for distilling-type heaters. To be satisfactory for use in orchard heaters,[1] however, a fuel must have certain qualities. The amount of residue formed in the bowls is affected somewhat by variations in fuel characteristics. For drip-

[1] Bowl-type or distilling-type heaters use gas oil generally known as bunker-grade marine Diesel fuel of 27+° A.P.I. (American Petroleum Institute) gravity. The refineries list this grade of oil as Pacific Standard 200, selected for low pour point. (For specification values of this grade of fuel see Warren R. Schoonover, F. A. Brooks, and H. B. Walker, "Protection of orchards against frost," California Agric. Ext. Serv. Circ. 111 [1939], p. 47.) The fuel used in the bowl-type heaters during the field tests reported herein had a gravity of 31.3° A.P.I., a 50 per cent distillation temperature of 508° F., and an open-crucible self-burning residue of 1.8 per cent (higher than the recommended maximum). The fuel used in the Kittle and Fugit heaters was a kero-distillate of approximately 38° A.P.I. gravity.

type heaters the amount of coking in the fuel troughs is increased by the use of poor grades of heater oil. The operation of generator-type heaters is sensitive to oil characteristics.

5. Wind: Stack-type heaters are more smoky in a breeze than in calm weather. Since this condition cannot be controlled by the grower, it need not be discussed further.

### SPRAYING AND IRRIGATION*

*Spraying.*—Spraying of trees with water to afford protection from frost has proved impracticable. The weight of the heavy coating of ice that is formed strips large branches from the trees and sometimes even splits the trunks. Spraying of low-growing plants may be effective if the temperature does not fall too low. Water must be sprayed on the plants continuously as long as the temperature remains below the danger point.

The belief held by many farmers and fruitgrowers that the temperature of a plant or tree encased in ice cannot fall below 32° F. is erroneous. If water is sprayed continuously over the entire plant so that freezing is continuous, the temperature of the plant is not likely to fall much below 32°; however, if the supply of water is cut off before the air temperature rises above the danger point, the plant may be severely damaged even though completely encased in ice.

*Irrigation.*—Fairly good results have been obtained by turning warm irrigation water into fields and gardens on moderately cold nights, and the flooding of orchards by the check or basin system has afforded protection against moderate frosts, but irrigation alone will not afford adequate protection during severe frosts. Running water in furrows in an orchard affords still less protection. Furrow irrigation in a California orange grove, using water with a temperature of 72° F. at the outlet, maintained the temperature at no more than about 1.5° F. above the outside temperature. Frequent irrigation of citrus trees in the winter months may injure the roots.

### STIRRING THE AIR

The temperature of the air 40 feet above the ground on a frosty night is often from 7° to 10° F. higher than that 5 feet above. It is obvious that if the air within this distance could be thoroughly mixed a safe temperature could usually be maintained. Large power-driven fans, mounted on towers, have raised citrus orchard temperatures over limited areas as much as 8°, under ideal conditions, with a strong natural increase in air temperature with elevation and a practically calm atmosphere. However, none of these machines will move air far against a moderate natural air drift; and during freezes or exceptionally heavy frosts, when protection is needed most, there is likely to be little or no increase in air temperature with elevation and no warm air to be brought down. No machine has been devised which will afford dependable protection during severe frosts.

* The following practical considerations of frost prevention are condensed from Young (1940).

## GENERAL RECOMMENDATIONS

The effectiveness of orchard heating, when properly handled, in preventing damage from frost in the Pacific Coast states and in Florida is no longer open to question. Of course, the use of orchard heaters is inadvisable anywhere unless it is justified by the returns from the crops.

Numerous schemes for orchard protection, such as central heating plants, and steam heat, have proved impractical. Orchard heating by many small heaters is at present the only efficient and successful method of protecting orchards from frost damage on a large scale.

The fact cannot be emphasized too strongly that if orchard heating is to be practiced successfully it must be handled with as much care and attention as spraying, fumigating, or any other necessary orchard work. The secret of success will be found in adequate equipment, good judgment, attention to detail, and extreme vigilance. An inadequate number of fires to the acre may often be worse than none at all, as the costs of firing may have to be added to the loss of the crop.

Heaters should be in place in the orchard, fueled, and all necessary preparations for firing made well before the danger period begins. Procrastination has cost millions of dollars in past years.

Whenever the temperature approaches the danger point, the thermometer in the orchard should be watched closely, and, if possible, the rate at which the temperature is falling should be determined. If the temperature is falling rapidly, the firing must be begun early so that the initial lighting can be completed before the danger point is reached.

Oil heaters (except the lard-pail type) should never be burned dry, as the bowls are likely to be warped and otherwise damaged by overheating.

When an orchard is being heated a safe temperature should always be maintained. Frost markings or partial destruction of the crop may result in a loss greater than the entire heating expense for the season.

Whenever it is possible, the owner of the property should supervise orchard-heating operations. Detailing of responsibility for protection of the crop to someone who has no direct interest in the result has been accountable for many failures.

The lighting and regulation of the heaters during the night and the refilling operations of the following day ordinarily are handled by two different labor crews. During emergencies such as that which prevailed in California citrus districts during the 1937 freeze, a shortage of available labor sometimes necessitates filling and lighting by the same men. In the course of filling operations, clothing usually becomes saturated with spilled oil, and a number of fatal accidents have occurred when oil-soaked garments have caught fire from burning heaters. Filling crews should not be permitted to work in the vicinity of any fire until dry clothing has replaced that on which oil has been spilled.

When stack heaters burn low on a cold night, necessitating refilling, or when refueling is begun immediately after the heaters are extinguished in

the morning, eare should be taken to insure the presenee of a live flame in the bowl. Refueling flaming heaters is a safe operation, but if the flame has been extinguished and sparks are still present in the soot in bowl or stack, gas explosions may eause serious aeeidents. If the heater has burned dry, a flame ean be started by pouring in fuel from a lighting toreh.

In loealities where orehard heating is an established praetiee and the eorreet methods of handling the firing are well known, most of the failures to save erops—and they are few—are ehargeable to earelessness. As a preeautionary measure it is well to do a little test firing at the beginning of the season, to make sure that the torehes and other equipment are in working order. Defeets may be found whieh ean easily be remedied in daylight, but whieh would eause the loss of mueh valuable time on a eold night.

The purehase of eheap thermometers is false eeonomy. The grower should buy good thermometers, graduated to single degrees, and guaranteed by the manufaeturer to be aeeurate within one-half degree.

Thermometers should be removed from the orehard at the end of the frost season and stored in a eool plaee in a vertieal position, bulbs down.

It is well to plaee a white stake at the end of the row in whieh a thermometer is plaeed, to facilitate making temperature readings.

On a eold night, an isolated eloud passing overhead may eause the temperature to rise, but as the eloud drifts toward the horizon the temperature falls again. Likewise, sudden temporary rises are caused by gusts of wind of short duration which mix the upper and the surfaee air. As a general rule, the temperature falls rapidly after the wind or cloud has passed; entire erops have been lost beeause heaters were not then in operation. If elouds are overspreading the entire sky, or wind brings a sudden rise in temperature just before sunrise, the heaters may be extinguished; but if the sky remains elear and sunrise is an hour or more away, the temperature should be watehed elosely the rest of the night.

Although it is sometimes diffieult to find time to keep reeords on heating operations during the rush of the firing, it should be done whenever possible. The temperature when firing is begun, the time of initial firing and the number of heaters fired, the time of firing additional heaters, and the lowest temperature reeorded during the night ean all be jotted down from time to time as the work goes on. On the following day an estimate ean be made of the amount of fuel consumed and the extent of the damage to the fruit, if any. Reeords of this kind will be of great value toward proper regulating of later firing; the more the information gathered, the more effieiently ean the firing be handled.

A good frost alarm of the elosed-eireuit type is quite dependable and will appreeiably reduee the time required for watehing during the night.

## ECONOMIC PHASES OF FROST PROTECTION

The eosts of orehard heating, ineluding equipment, fuel, labor, and so on, vary in different parts of the United States, as likewise the temperatures and the weather eonditions whieh aeeompany damaging frosts. The quality and

quantity of the fruit produced and the prices received for the crops also vary, not only in different districts, but also in different orchards in the same district. It is impossible to make a general statement on the advisability of installing orchard heaters.

Heating must be regarded as a form of crop insurance. The yearly premium on the policy is the total average annual cost of the heating, including interest on investment and depreciation charges. Insuring the fruit crop by installing orchard-heating equipment cannot be directly compared with insuring a house against damage by fire, for it is reasonably certain that the fruit crop will be damaged by frost every few years, whereas insurance on a building may be carried for a generation without fire damage. As a general rule, in years when orchard-heating expenses are heaviest, there is a shortage of first-grade fruit that brings better than average prices.

## PROBABLE COSTS

Since there is a great variation in the cost of orchard heating in different parts of the country, and even in different orchards in the same district, because of differing costs of equipment, fuel, labor, and the like, and to differences in the frost hazard, it is possible to give only a few examples of actual cost accounts supplied by fruitgrowers or by corporations.

Orchard heating has been practiced for more than thirty years in one of the largest lemon orchards in the country, in southern California. In the winter of 1912–13, a season when the citrus crop in many parts of southern California was practically a total loss and thousands of trees were killed outright in unheated orchards, the crop from this 281-acre grove brought $734,318.07 f.o.b. California. The manager states, as his considered opinion, that this orchard could not have been profitable since 1912 without means of protection from frost. On higher ground on the same property where protection had not been considered necessary, another orchard, of 5-year-old lemon trees, was frozen to the ground.

This orchard property is on both high and low ground, but only the low ground is protected. Lemons are damaged at higher temperatures than oranges, and since the small green fruit, which is especially tender, is protected here, the heaters are lighted oftener and kept burning longer than in most other orchards. The costs of frost protection here are thus for firing about the maximum number of times that would be necessary anywhere.

Records on the cost of protecting 281 acres on this property during a 14-year period are shown in table 50. It will be seen that the return from the fruit saved in 1913 alone, despite the high rate of heating expense, would pay the costs of protection for many years.

At present (1948), prices have not stabilized sufficiently to permit accurate estimates of costs of orchard heating. Manufacturers of orchard-heating equipment are selling items subject to price at time of delivery and labor, and oil costs are uncertain. However, for the grower who must decide whether to heat or not, a summary of average costs during the prewar year 1940 is given in table 51.

TABLE 50

COSTS PER ACRE FOR PROTECTING A LEMON ORCHARD[a]

(Small open heaters used in 1913; improved stack oil heaters used in later seasons.)

| Year | Number of times firing necessary | Average costs per acre | | | | | Total cost per acre |
|---|---|---|---|---|---|---|---|
| | | Labor for filling, lighting, and maintenance | Oil burned in heaters | Depreciation | Interest | Upkeep | |
| 1913 | 19 | $45.70 | $38.35 | $19.30 | $17.85 | $11.55 | $132.75 |
| 1914 | 2 | 10.55 | 12.70 | 19.10 | 17.45 | 7.95 | 67.75 |
| 1915 | 7 | 10.65 | 4.20 | 17.40 | 15.50 | 7.65 | 55.40 |
| 1916 | 20 | 21.45 | 23.20 | 15.60 | 13.40 | 1.10 | 74.75 |
| 1917 | 27 | 20.60 | 26.15 | 14.30 | 13.45 | 5.65 | 80.15 |
| 1918 | 21 | 22.15 | 17.75 | 13.00 | 11.25 | 3.70 | 67.85 |
| 1919 | 14 | 17.14 | 5.53 | 13.09 | 8.62 | 3.44 | 47.82 |
| 1920 | 12 | 20.54 | 5.83 | 13.44 | 10.80 | 1.51 | 52.21 |
| 1921 | 15 | 26.66 | 6.40 | 13.44 | 10.62 | 5.49 | 62.67 |
| 1922 | 11 | 27.24 | 6.34 | 20.67 | 11.36 | 2.77 | 68.38 |
| 1923 | 30 | 47.40 | 21.99 | 21.44 | 10.70 | 3.00 | 104.53 |
| 1924 | 27 | 39.92 | 22.26 | 21.46 | 9.55 | 1.31 | 94.50 |
| 1925 | 17 | 29.14 | 12.48 | 21.46 | 8.80 | 1.49 | 73.37 |
| 1926[b] | 13 | 18.27 | 8.70 | 4.83 | 0.28 | 1.14 | 39.22 |
| Average | 17 | $25.53 | $15.14 | $16.32 | $11.84 | $ 4.12 | $ 72.95 |

[a] The data presented are for a 281-acre orchard.

[b] In 1926 a new method of accounting was adopted. Cost figures for that year are based on a total of 682 acres of lemons heated.

TABLE 51

AVERAGE COSTS FOR EQUIPPING AND PROTECTING FIFTY ACRES OF ORANGES IN SOUTHERN CALIFORNIA WITH DOUBLE-STACK OIL HEATERS

INITIAL COST OF EQUIPMENT

| | | |
|---|---|---|
| **Heaters:** | | |
| 2,800 double-stack oil heaters, 9-gallon size, at $2.32 each, delivered | $6,496.00 | |
| 12 lighting torches, 1-gallon size, at $2.50 | 30.00 | |
| | | $ 6,526.00 |
| **Storage:** | | |
| 105,000-gallon galvanized-iron tank | 1,179.00 | |
| Concrete foundation for tank | 50.51 | |
| Container for lighting fluid, 50-gallon size | 3.00 | |
| | | 1,232.51 |
| **Distributing system:** | | |
| 2 tank wagons, 450-gallon size, at $150 | 300.00 | |
| Pipe line from storage tank to orchard | 209.13 | |
| Tank-wagon accessories: pipes, connections, valves, hose, buckets, etc. | 50.00 | |
| Portable pump for emptying heaters | 20.00 | |
| | | 579.13 |

TABLE 51 (*Continued*)

| | | | |
|---|---|---|---|
| Thermometers: | | | |
| 12 minimum-recording thermometers at $3 | | $ 36.00 | |
| 1 frost alarm | | 30.00 | |
| 5 flashlights at $1.50 for thermometer reading | | 7.50 | |
| | | | $ 73.50 |
| Fuel: | | | |
| 1,000,000 gallons heater oil in tank, at $0.04 | | 4,000.00 | |
| 40 gallons lighting fluid (kerosene and gasoline) at $0.20 | | 8.00 | |
| | | | 4,008.00 |
| Total investment | | | $12,419.14 |
| AVERAGE ANNUAL OPERATING EXPENSE | | | |
| Interest: | | | |
| 3 per cent on $8,411.14, investment in equipment[a] | | $ 252.33 | |
| 6 per cent on $4,008, investment in fuel | | 240.48 | |
| | | | $ 492.81 |
| Depreciation: | | | |
| Heaters, 10 per cent on $6,526 | | 652.60 | |
| Storage, 5 per cent on $1,232.51 | | 61.63 | |
| Distributing system: | | | |
| Tank wagons, 10 per cent on $300 | $30.00 | | |
| Pipe line, 3 per cent on $209.13 | 6.27 | | |
| Accessories, 20 per cent on $70 | 14.00 | | |
| | | 50.27 | |
| Thermometers: | | | |
| 5 per cent on $73.50 | | 3.68 | |
| Fuel: | | | |
| Leakage and evaporation, 1½ per cent of total store, or 1,500 gallons at $0.04 | | 60.00 | |
| | | | 828.18 |
| Operation: | | | |
| Setting pots in orchard | | 38.00 | |
| Filling pots | | 70.35 | |
| Refilling pots after firing (10 times) | | 116.02 | |
| Lighting pots (10 times a year) | | 160.00 | |
| Taking up oil at end of season | | 90.57 | |
| Taking up heaters | | 32.43 | |
| Painting heaters every 4 years at $0.16 each a year | | 112.00 | |
| | | | 619.37 |
| Fuel: | | | |
| 17,129 gallons oil burned in heaters at $0.04 | | 685.16 | |
| Lighting fluid, 28 gallons at $0.20 | | 5.60 | |
| | | | 690.76 |
| Average annual cost for 50 acres | | | $ 2,631.12 |
| Average annual cost per acre | | | $ 52.62 |

[a] Since there is an average annual depreciation rate of 10 per cent on all items of equipment, a fixed interest charge of 3 per cent per annum on the total investment will provide for a yearly charge of 6 per cent on the depreciated value.

### PROBABLE BENEFITS

The question whether orchard heating will pay at a given location depends largely upon the amount and quality of the fruit produced. The cost of protection is the same for a given orchard whether the trees are young or old and whether a heavy crop of good-quality fruit or a small inferior crop is produced. Quantity and quality production must always be considered. Average prices received for the crops are also a factor.

If the net profit on a crop were the only consideration in determining whether frost protection will pay, the answer must be negative for most

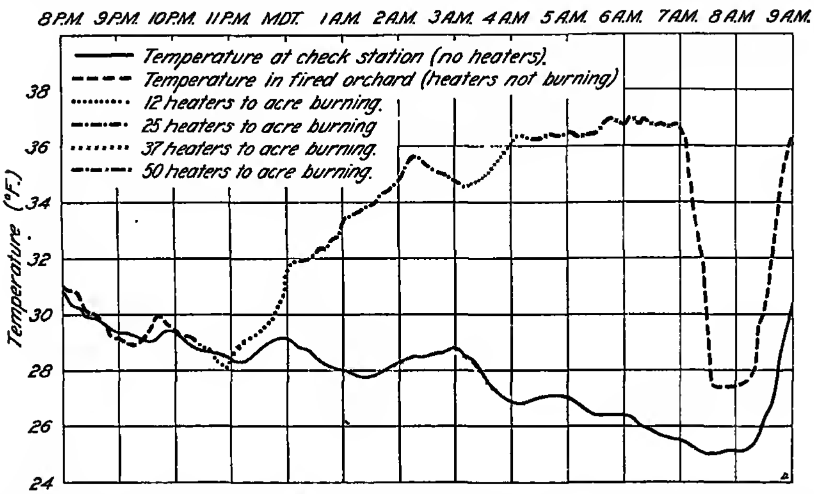


Fig. 283. Continuous records of the temperature in an orange grove equipped with 50 double-stack oil heaters to the acre, and at a check station outside, during test firing on a frosty night. No heaters were burned near the temperature station in the heated grove. The solid line indicates what the temperature in the fired orchard would have been without heating. The temperature was raised 11° F., with 50 heaters to the acre burning.

fruitgrowing districts in the country. However, when a fruit crop is destroyed by frost the owner's loss is not limited to the net profit he would have made on the crop; the expense of caring for the orchard for a year, interest on the money invested in the orchard, and other similar expenses must be added.

The amount of the loss, therefore, will be the gross value of the crop less the expenses of picking, packing, and so on. The loss calculated on this basis is often very large. Many fruit growers have saved enough fruit in a single season, or even a single frosty night, to pay the total cost of equipping the orchard with heaters and auxiliary equipment, together with the expenses of protecting the orchard during the season. The rise in temperature caused by using orchard heaters on a typical cold night is shown graphically in figure 283.

Frost damage to trees is a very important consideration. Orange and lemon trees are sometimes defoliated by a heavy freeze and often require five years or longer to get back to normal production again. In some districts, hundreds of acres of citrus trees have been killed outright by low temperatures.

There are two conditions under which orchard heating will not be profitable: the orchard may be situated where frost damage is too slight in the long run to pay the expenses of heating; or it may be in an exceptionally cold region, where damaging frosts occur so often that the cost of protection is too great to be borne by the crops. The condition first given is rarer than would appear at first thought. The saving of one season's crop, which would otherwise have been a total loss, will justify the expense of heating for several years. Many practical growers consider it good business policy to have frost-fighting equipment when it is necessary to use it only one season out of five. As for the second condition, it is obvious that the frost hazard is so great that fruitgrowing will not be profitable in the long run and the trees will eventually have to be removed.

The statement is often made that the policy of growing fruit on the colder low ground is wrong and that orchards should be limited to the higher and more frost-free locations. This is often open to question. Certain fruits, such as the navel orange, are of better quality when grown in localities where the temperature falls almost to the danger point at times. In many irrigated sections the lower cost of irrigating the valley floor as compared with steep hillsides more than makes up for the expense of protecting orchards on the lower ground from frost. Also, the cost of cultivating steep hillsides is greater, and valley soils often are more fertile than hillside soils.

In the event of a general severe freeze which reduces the total supply of fruit in the country, the crops saved by orchard heating tend to maintain more reasonable prices to the consumer. In this way frost protection benefits the entire country. For example, less than 50 per cent of the normal citrus crop was harvested in California in 1922 because of a severe freeze; yet the delivered value of this crop was 75 per cent of normal. Consumers, because of the freeze, paid $30,000,000 more for the same amount of California citrus fruit in 1922 than in 1921. The total cost of the freeze to the consumer was much greater than this, because of the higher prices paid for the Florida crop. Losses to railroads from decreased freight receipts were approximately $20,000,000. Even the relatively small acreage of citrus equipped with orchard heaters in 1922 materially increased the amount of undamaged fruit and undoubtedly had its effect in preventing even higher prices to the consumer.

An unusually short crop of any variety of fruit may adversely affect its orderly marketing. The ideal condition would be the steady production of good-quality fruit in amounts which would bring a fair return to the grower year after year. A short crop is likely to cause such high retail prices that the public turns to other fruits, and the cumulative effect of advertising, such as has been done in popularizing citrus fruits, may be lost, temporarily at least.

Although state and federal laws impose rigid restrictions on the shipment of badly frozen citrus fruits, large quantities of slightly frozen fruit reach the markets after an unusually cold season. This also tends to decrease the consumption in general and is likely to result in a smaller demand and lower prices for excellent-quality fruit the following season.

A severe freeze sometimes has an adverse effect on coöperative-marketing organizations. From 85 to 90 per cent of the citrus crop in California is handled through coöperative agencies. These agencies, from the packing houses to the eastern sales organizations, are financed through an assessment on each box of fruit marketed. After a strong organization has been built up through years of effort, it is obviously not possible to reduce the operating expenses to the same extent the crop is reduced when there is heavy frost damage; even a slight retrenchment is likely to weaken the organization. Therefore, the cost of carrying the coöperative through a freeze year is borne largely by the growers who have saved their crops, and the per-box assessment for coöperative-marketing organizations is greatly increased.

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## CHAPTER XVIII

# EFFECTS OF FREEZES: TREATMENT AND RECOVERY OF INJURED TREES

BY

HENRY J. WILDER

CITRUS TREES are tender subtropicals, but the most successful areas of commercial production are, in general, near the highest latitudes at which their extensive culture is possible. This is principally true in both the Northern and Southern Hemispheres. (Consult Vol. I, chap. iii.) It thus arises that in almost all the principal citrus-producing sections of the world the trees and fruits are subject to more or less damage by occasional freezes.

Since the introduction of citrus-fruit culture into the Mediterranean countries of Europe in the early days of the Christian era, more or less attention has been given to the study of frost protection and to the treatment of frost-injured trees. In most sections, however, severe freezes are so infrequent that each recurring freeze finds many growers unprepared and uninformed of the best treatment for injured trees. The discussion presented here is limited to consideration of the effects of freezes and the treatment of injured trees. Injuries to the fruit and fruit-salvaging methods will be discussed in a later volume of this work.

## FREQUENCY OF DAMAGING FREEZES

In Florida, damaging freezes are known to have occurred in the winters of 1747, 1766, 1774, 1799, 1828, 1835, 1850, 1857, 1880, 1884, 1886, 1894, and 1895 (Webber, 1896, p. 161), 1899, 1905, 1917, 1928, 1934. and 1940 (U. S. Weather Bureau, 1935, p. 106). This indicates that a severe freeze has occurred approximately every ten years during the last two centuries. All these freezes were not of equal severity, and in the course of the two centuries many lesser freezes are known to have occurred. All the major freezes in the years mentioned must have caused damage where citrus groves existed, but the most severe injuries occurred in the great freezes of 1835 and the two freezes of the winter of 1894–95.

In California, also, damaging freezes occur about every ten years, and minor freezes more frequently. Here, where citrus acreage did not expand in the last hundred years so rapidly as in Florida, there was a good deal of damage in 1894, and very heavy damage in 1913 and 1922. The years 1932 and 1937 also had low temperatures, though the damage was much less, owing in part at least to the great increase in orchard-heating equipment after the 1922 freeze, and to its more efficient use. In 1937, injury resulted because not enough tank cars were available to meet the oil-distribution needs of the industry in the emergency. This emphasized, not only that every grower should be provided with adequate oil storage, either on his own initiative or

through an association connected with his packing house, but also that storage tanks should be kept filled to capacity (see chap. xvii, above). It may be noted that the need for adequate artificial heating was clearly recognized as early as 1908–09, since it was in that season that a small group of growers in the Pomona district installed some crude oil-burning heaters. In 1911–12 the protected groves had increased to about 750 acres. On May 15, 1912, the Pomona Valley Orchard Protective Association was formed; and this was probably the first frost-fighting coöperative.

The citrus-growing sections of the United States in Texas, Arizona, Louisiana, Alabama, Mississippi, and Georgia are also subject to periodic freezes; and in all these areas, except in extreme southern Texas and parts of Arizona, the cold is likely to be more severe than in California or Florida. (See temperature data for these sections in Vol. I, pp. 84–86.) Frost damage is also an important problem in almost all the large citrus-producing areas of the world.

Frost damage to trees in the various citrus-growing districts of the United States is a fairly frequent occurrence; hence it is important that every grower know the best methods of handling damaged trees. The majority of citrus orchards are not provided with heating equipment; and in those that are so provided, unavoidable conditions or accidents may permit damage to occur—the oil-storage or refilling equipment may prove insufficient, thermometer readings may not be adequately interpreted, or a sufficient number of orchard helpers may not be available when temperatures drop rapidly and remain low. Although much progress in installing orchard-heating equipment has been made in California since the freezes of 1913 and 1922, a heavy freeze still does damage, some of which could be avoided if such conditions as those mentioned above were adequately provided against.

## PLANT CHARACTERISTICS IN RELATION TO FROST INJURY

### SYMPTOMS OF FROST INJURY

During periods of low temperatures the leaves of orange trees commonly assume a slightly crinkled, drooping appearance, but remain firm and brittle if frozen. Leaves of the lemon, however, retain their normal appearance even though badly frozen. As they thaw after the freeze, the leaves at first become slightly flabby, but, if not too severely frozen, they gradually regain normal turgidity and recover. Seriously frozen leaves, however, gradually collapse and dry out, turning brown in patches or throughout. The youngest leaves are the most easily injured, but all the leaves may be killed in a severe freeze. If the twigs are seriously frozen, the leaves commonly dry out and remain attached until they are accidentally broken or blown off. If, however, the twigs are not seriously injured, a separative tissue layer is formed at the base of each leaf petiole and the injured leaves are thrown off rather promptly.

The twigs, branches, and trunk of a tree are commonly resistant to injury from freezing in proportion to their diameter. Small, young twigs that still remain green are less resistant than more mature twigs with gray bark, and

these in turn are less resistant than the large limbs. The trunk is commonly the most resistant part of the tree above the ground, but the area near the bud union is commonly more subject to injury than other parts of the trunk. This is particularly noticeable in Florida, less so in California.

In young twigs that are still green, frost injury is first indicated by their turning a darker green in color throughout, or in patches; if severely injured, they dry out rapidly and turn brownish in a few days. In light freezes, a tree may lose a large proportion of its leaves and show only a small amount of twig injury. In severe freezes, large trees may be killed to the ground, but the underground part of the trunk and the roots are rarely if ever killed; if they do not sprout from the base quickly, however, they may die as a result of the shock and the lack of the nutrition normally supplied through the foliage. If young twigs are seriously injured, it is almost certain that the fruit has also been injured. If trees are not injured enough to cause a drop of a large part of their foliage and young twigs, it is not likely that any large amount of the fruit will be frozen and hence found unsatisfactory for shipment. (Frozen-fruit characters will be discussed in a later volume.)

### TREE CONDITION IN RELATION TO DEGREE OF INJURY

*Dormancy of trees.*—That trees which are in active growth are much more seriously injured by freezing than those which are dormant is a conclusion based on the wide experience of growers and students in many localities. No definite data are available to indicate the difference in degree of cold that a dormant tree can endure, but marked difference in the amount of injury to such trees can be observed in every damaging freeze. Dormancy in citrus and other trees is usually induced by the approach of cold weather, when the temperatures gradually fall below those required for growth (about 55° F. for citrus; see Vol. I, p. 58) and the trees become inactive. A similar condition of inactive growth may also be induced by lack of water, or by drought.

Commonly, dormancy is produced by natural conditions and cannot, in general, be effectively controlled by growers; but in regions subject to frequent frost injury some degree of control may perhaps be exercised. Any treatment that stimulates tree growth or activity in the late fall or early winter should be avoided. The following operations, if conducted in the fall, commonly tend to stimulate late growth: irrigation, cultivation, fertilization, and especially, pruning. Withholding any such treatments to the point of arresting growth may, however, be injurious. Orchards suffering from lack of water if a freeze does come are more severely injured than those with optimum or normal moisture. Cultivation and fertilization can usually be safely omitted in late fall. Pruning weakens the tree, stimulates new growth, and ordinarily should be delayed until early spring when the danger of freezes is past. After the freeze of 1913 in California, trees that had been pruned in the fall before the freeze were seen to be much more severely injured than adjacent similar trees that had not been pruned (Webber *et al.*, 1919, p. 279).

It is evident that little protection can be achieved through artificially induced dormancy; and in localities where efficient heating is practiced it is probably not good practice to consider any methods of inducing dormancy. Even so, however, it is apparently desirable to avoid pruning in late summer or fall, because the pruning is likely to stimulate a vigorous growth that will render the trees more susceptible to injury.

Heavy frost damage in California or Florida is more serious in December than in February. If there is heavy leaf drop in early winter, new growth is likely to develop and render the trees extremely tender and easily subject to damage from later cold spells. The relative inactivity or dormancy of the tree during the normal winter, however, makes that its most cold-resistant stage. Temperatures that will just defoliate such trees will not kill angular wood; and if they are low enough to kill angular wood, they must fall yet lower to kill round, more mature wood.

*Effect of tree vigor on freeze injury.*—Trees that are debilitated from any cause and lack vigor are invariably more seriously injured by freezes, and slower to recover, than trees in normal condition. Trees having infestations of scale insects or red spiders, and trees attacked by gummosis, scaly bark, or other diseases, are more seriously injured than adjacent healthy trees. Debilitation is most easily observed in single trees; but frequently it occurs throughout entire orchards. An orchard that is run down in vigor by neglect, insufficient irrigation or fertilization, poor pest control, or any similar cause, always shows more serious damage from freezing than one that has been given good care and is in good vitality and health.

Healthy trees that have recently undergone treatment that reduces their vigor also exhibit greater injury. Vigor-reducing treatments include fall pruning; scoring or slitting the bark on the trunks of young trees, which is erroneously supposed to promote growth; and, sometimes, excessive girdling to promote fruitfulness (Webber *et al.*, 1919, p. 279).

*Effect of fertilization on freeze injury.*—As tree vigor influences the degree of injury in freezes, it follows that malnutrition or insufficient nutrition which decreases tree vitality will increase the damage. Results of careful studies made at the Florida Citrus Experiment Station, Lake Alfred, on the degree of injury caused in the freeze of January, 1940, on trees in experimental fertilizer plots (Camp *et al.*, 1940; Lawless and Camp, 1940; Lawless, 1941) supply an enlightening illustration.

It has been found that in Florida soils certain minor fertilizing elements are important contributors to vigor of growth, particularly copper, zinc, manganese, and magnesium, when they are used in addition to nitrogen, phosphorus, and potash. For the frost-injury studies cited above, plots were available in which the three fertilizer elements, nitrogen (N), phosphorus (P), and potash (K), until recently considered to constitute the essential fertilizer elements, were supplemented with one, two, three, or all four of the minor elements. (For details of these observations see chap. vii, p. 366.) The greatest damage was sustained by those fertilized only with nitrogen, phosphorus, and potash; the least, by those receiving these elements and in

addition all four of the minor elements, Zn, Cu, Mn, and Mg. The authors, in summarizing their observations, stated: "The indications from . . . the plots at the Citrus Experiment Station, and groves in general, are that any deficiency is likely to predispose trees to cold injury and that copper and magnesium are particularly important in this connection. . . . Our whole experience merely tends to further stress the importance of supplying all the nutritional needs of the trees." (Lawless and Camp, 1940, p. 125). The authors interpret the protective influence as due to the more vigorous condition of the trees induced by good nutrition, rather than to any particular virtue in any element that determines cold resistance.

Thus far, the citrus soils of California have not shown a need for applications of magnesium, but commonly have shown deficiencies of zinc, and, in some restricted areas, deficiencies of manganese or copper, so far, at least, as trees have responded to treatments with these elements. What constitutes good nutritional conditions will vary widely in different citrus-growing districts. (See chap. vii, on "Principles and Methods of Fertilization.")

*Relation of irrigation to tree injury.*—Observations made after the freeze of 1913 in California (Webber *et al.*, 1919, p. 278) seemed to indicate that the moisture content of the tree (turgescence) had an influence on the degree of injury. Trees that had been allowed to dry out so far as to show drought injury were more severely frozen than trees with normal or optimum turgescence.

At the time of the very severe freeze which occurred round about Oroville, California, from December 9 to 15, 1932, when minimums of 12° F. to 15° F. were recorded, many orchards were in a very dry condition,[1] since the fall rains had been delayed long beyond their normal time. Orchards that had been irrigated late and had thus retained a sufficient amount of moisture were injured less than those which had been allowed to become too dry. There is an important lesson in this for California growers in the interior counties, who sometimes postpone a late fall irrigation, anticipating that rain will soon come.

When the soil approaches dryness, it should be irrigated. Waiting for rain will then be hazardous, not only because the degree of moisture present is inadequate, but also because the possible frost damage may be severe. California orchards have at times been badly affected when irrigation was thus postponed.

In Florida also it has been noted that, temperatures being the same, damage from cold is more serious with continued dry weather than when rainfall is ample (Kime, 1935).

Observations have also been made which indicate that trees irrigated shortly before a freeze (10 to 14 days), so that they are highly turgid with water, tend to be more injured than those somewhat more dried out. It seems probable that there is an optimum degree of turgidity at which the trees are less injured than when they are either too dry or too moist. These conditions, however, are

[1] Verbal information from the late Dr. H. J. Webber.

so complex that it is probable they cannot often be considered when frost protection is undertaken.

*Relation of cultivation to tree injury.*—Cultivation is also supposed to stimulate growth; but this is open to question. Cultivation necessarily results in the cutting of some roots, and the tree is probably at first "thrown off balance" and reduced in vigor, which may render it slightly more susceptible to frost injury. Although it seems certain that cultivation itself has little influence on the susceptibility of trees to injury from cold, it is probably good practice to avoid all tillage in the fall, other than that necessary in preparing for winter cover crops.

*Influence of shade trees on freeze injury.*—When the full effect of the January, 1937, freeze in California became visible, it was observed that grapefruit, orange, and tangerine orchards interplanted in date gardens were much less severely injured than adjoining orchards planted in the open (Webber, 1937*a*). The interplanted citrus trees under the palms, uniformly throughout the Coachella Valley where this combination culture is practiced, retained their foliage almost untouched and showed no appreciable twig and branch injury (the fruit had been harvested before the freeze). Such interplanted orchards were scattered throughout the valley for a distance of thirty miles, and official weather records indicated, for the district, minimum temperatures of 12° to 15° F., of several hours' duration. Grapefruit and tangerine orchards planted alone frequently adjoined such interplanted gardens and were uniformly injured: almost the entire foliage and many of the twigs and small limbs were killed. The contrast in appearance between these orchards and those interplanted in date gardens was pronounced.

The explanation of these differences is not thoroughly understood, but supposedly they are attributable, at least in part, to the fact that an earlier and more thorough dormancy was induced in the citrus trees by their growing in shade, at a reduced temperature, and with greater competition for moisture. It is also probable that the reduced heat and light were favorable for the best possible recovery of frost-injured tissues.

It seems also probable that the tops of the palms hanging over the citrus trees screened them from the clear sky and thus reduced the loss of heat by radiation from the trees to the sky.

Lawless and Camp (1940, p. 122) observed in Florida that some citrus trees growing in shade under a clump of pines lost only a few leaves, whereas unprotected trees a few feet away in the same orchard suffered a heavy loss of wood.

*Varying degrees of susceptibility.*—That the species of *Citrus* differ considerably in their comparative degree of resistance to freezing is well known. Trees of the citron, lime, and lemon are more tender than those of the grapefruit and sweet orange, and these in turn are more tender than sour orange and mandarin orange trees. The kumquat and the trifoliate orange, which belong in genera closely related to *Citrus*, are still more hardy. The fruits of the various species exhibit some differences in degree of resistance to that shown by the trees. The fruits of the mandarin orange, for instance, are much

more easily injured by frost than those of the grapefruit or the pummelo. (See Vol. I, p. 54.) These differences in the degree of resistance to freezing exhibited by the species are of great importance when a grower is choosing the type of citrus to plant in a certain location in order to avoid loss through freezing. Citrons, limes, and lemons should be planted only in the warmest areas available, oranges and grapefruits being placed in the slightly colder sections.

The degree of hardiness referred to in the preceding paragraph is constitutional (genetic) for each species and is independent of, but affected by, the environmental conditions discussed in preceding sections. It is probably closely related to dormancy, and the tendency shown by some species more than others to remain thoroughly dormant throughout the cool winter period. The citron, lime, and lemon tend to be continuous growers and fruiters and are frost-tender species, whereas oranges, grapefruits, and mandarins have more definite periods of growth and fruiting, exhibit a greater tendency to remain dormant during the winter, and are more frost-hardy.

After every freeze it is possible to observe that certain trees in an orchard of the same variety have been less injured than others, and sometimes a single tree will go through a freeze almost untouched while the others surrounding it are defoliated and badly injured. Many such trees have been chosen and propagated as *frost-proof* varieties. The clonal (bud) progeny of all, or almost all, such selections have failed, however, to exhibit any greater hardiness than that characteristic of the varieties from which they originated. It is of course entirely possible that a tree showing such resistance may have originated as a bud sport and would transmit its character of hardiness, but that would constitute a major change in the variety, since there is but slight difference in degree of hardiness among the many varieties of any certain citrus species. A contradiction might be argued for the hardy Meyer lemon; but that variety is probably a hybrid and not a pure lemon. Apparently, the resistance of such seemingly *frost-proof* trees is to be explained usually as a difference due to the special conditions of a narrowly limited local environment, which have rendered them more dormant than neighboring trees.

*Effect of rootstocks and interstocks on freezing injury.*—Since this subject has been fully discussed earlier (see chap. ii, pp. 94–95), little need be added here.

Rootstocks comprise mainly the underground parts of the tree only, and even the least cold-resistant ones are but rarely injured in the most severe freezes; hence they are to be considered mainly with respect to their effect on the scion variety as influencing its degree of resistance. The rootstocks of nursery trees and young orchard trees, however, if these are more tender and frost-susceptible than the scion variety, may sometimes be frozen severely while the tops are but little injured. Injury of this kind can be successfully prevented by banking earth around the trunks to a short distance above the bud union, or by using frost-resistant stocks. Banking with earth also prevents injury to the bud-union area. In some citrus-growing regions, as in Florida, the bud-union area of citrus trees is commonly more susceptible to frost injury than other parts of the trunk or stock.

## NOTABLE FREEZES: TREE INJURY AND METHODS OF TREATMENT USED

Such widely varying conditions exist in different localities with each freeze that the degree of injury and the methods of tree treatment found to be the most satisfactory may be quite different. For this reason the discussion here relates to several of the most notable freezes and the lessons derived from studies subsequently made.

### THE FREEZES OF 1894–95 IN FLORIDA

*Character of the freezes.*—What is generally referred to as the great freeze of 1894–95 in Florida was really two freezes of about equal severity that occurred in one winter. The first began on December 27 and was most intense on December 29, 1894, when minimum temperatures (in degrees F.) recorded for well-known stations from north to south were: Jacksonville, 14° ; De Land, 16° ; Orlando, 18° ; Tampa, 19° ; Fort Myers, 24° ; and West Palm Beach, 24°. At most points in the citrus belt of that period the minimum temperatures ranged from 15° to 19°. F. Although all fruit was frozen solid, it remained firm for a month, and much of it was eaten locally and some was shipped to northern markets (Webber, 1896). Eventually, however, the crop that remained on the trees was almost wholly lost. The low temperatures were accompanied by strong winds which at most stations reached a maximum velocity of 25 to 30 miles per hour. Throughout most of the state, all leaves were killed, but, owing to weather conditions, dropped gradually. The trees were mostly dormant; hence there was only moderate twig injury and bark splitting (fig. 284).

The second freeze followed, February 7–9, 1895, with minimum temperatures, in general, about the same as in the first freeze (Jacksonville, 14° ; Orlando, 19° ; West Palm Beach, 29° F.). The five weeks intervening between the two freezes had been fair growing weather, and the two weeks immediately preceding the second freeze had been especially warm and good growing weather. As a result, growth had started and young shoots had pushed out abundantly all over the trees. Thus, the trees were very susceptible to damage by low temperatures when the second freeze came. As most of the old foliage had dropped from the trees, they were unprotected and in a very weakened condition. The oldest and youngest trees, whether on sweet stocks or sour stocks, were alike killed to the ground throughout the greater part of the state (fig. 285). This was true of large budded and seedling orange trees from twenty to forty years old (Webber, 1896). As this freeze probably caused greater damage to citrus than any other anywhere, it is of special historic significance. The following statement, prepared by Dr. Webber,[1] who made a special study of this freeze, is therefore included here.

"It is important to note that the great destruction wrought by the freezes of 1894–95 in Florida is of very rare occurrence and must be considered as phenomenal. It was the combined result of two freezes so spaced and corre-

[1] H. J. Webber, University of California Citrus Experiment Station, Riverside, in a statement supplied to the writer October 29, 1944.

Fig. 284. Orange grove at Sanford in central peninsular Florida, after the freeze of 1894–95. All fruit was lost and the trees were killed to the ground. (Photo April, 1895, by H. J. Webber.)

Fig. 285. Orange grove at Fort Mason, in central peninsular Florida, killed to the ground in the freeze of 1894–95. The trees were cut back six months after the freeze. (Photo, September, 1895, by H. J. Webber.)

lated with otherwise good growing weather conditions as to produce the greatest possible damage. The citrus crop in Florida the year preceding the freeze, 1893–94, was recorded as 5,055,367 boxes; that of the year of the freeze was estimated at over 6,000,000 boxes, most of which was frozen; the crop of the following year, 1895–96, was only 147,000 boxes, all of which was produced in the extreme southern part of the state. It was not until the season of 1909–10, fifteen years later, that a crop was again produced equal to that of 1894–95, lost in the freeze. So far as known, no freeze or other catastrophe so disastrous to the citrus industry has ever occurred anywhere, at any time. Yet there was no call for aid, and no assistance provided to growers by state or nation. The only comparable freeze that has occurred in Florida was that of 1835, and the records of that freeze are so fragmentary that safe comparisons cannot be made; at that time there were only a few small citrus plantings in the state.

"In a single freeze of the same severity as either of those of 1894–95, the crop of the ensuing year is almost invariably heavier than the crop of the year preceding the freeze. This was true of the crops in Florida in the years following the severe freezes of 1886 and 1917 and of the crops in California following the freezes of 1913, 1922, and 1937. This reaction is difficult to understand in view of the almost total loss of foliage, young twigs, and even fairly large limbs. The shock to the trees seems to stimulate the setting of fruits from the flowers that form abundantly on the young growth of the early spring, which with an uninjured root system is forced into very vigorous growth."

*Rebuilding frozen trees.*—Since little experience had been accumulated from previous freezes, the problem of what methods to use in recovering or rebuilding the frozen trees in Florida in 1895 was a puzzling one. A wide variety of pruning treatments were tried. Many growers were so uncertain, however, about the best thing to do, and so discouraged, that they did nothing to the injured trees, and thereby discovered that trees left unpruned recovered more rapidly than those treated by any method of immediate pruning. This was observed particularly in the small area planted in the southern part of the state below the latitude of about 27°, and in other small protected areas, where the trees were not so severely injured. In the greater part of the state, however, the budded tops of the trees were entirely killed, and the main problem was how to reconstruct the scion tops most quickly and satisfactorily. The most common, and in general probably the most successful, method followed was to permit sprouts to develop from the base of the old stock trunks and, when they were sufficiently large, to bud several of the best-located of these on each tree with buds of the scion variety desired. The budding was usually done in May or June. The old dead trunks were most commonly cut off before the sprouts were budded, but all sprouts that grew from the bases of the old trunks were allowed to remain for a time to nourish the roots. All unbudded sprouts were removed when they began to interfere with the development of the budded sprouts.

Many methods of grafting were also used in the reconstruction of the tops of badly frozen trees, such as crown grafting, cleft grafting, and sprig grafting (see chap. i, above), but none of these methods proved as commonly

successful as the sprout-budding method. Grafting methods are more expensive because they require scions with five or six buds each, and budwood is scarce, especially under such conditions. Dr. Webber,[1] who conducted a special survey of the results of the 1894–95 freeze in Florida (Webber, 1896), has outlined the following example of the successful use of the crown-grafting method in recovering old trees, frozen to the ground.

"The most rapid rebuilding of old trees frozen to the ground . . . was in the grove of Dudley W. Adams (at that time president of the Florida State Horticultural Society), south of Lake Dora, in central peninsular Florida. Adams believed that the trees would ultimately die to the ground, and thus did not wait to see how they would recover. In the early spring as soon as the first sprouts began to show he had the old trunks sawed off slightly below the ground level. As the tops were removed, each old stump was crown-grafted with three or four scions to each stump, and the earth filled in around and over the stump covering the bases of the scions. As this work was done promptly, the main spring growth went into the scions and the development was thus considerably ahead of that in groves where sprouts were allowed to develop from the base of the trunk and then budded. This grove of Adams during a period of at least three years was considerably ahead of any other reconstructed grove observed in the survey. (See Webber, 1896, figs. 19, 20, and 21.)"

When the first freeze started, a few growers banked their trees with earth, thus covering the bud unions and the lower part of the scion trunks. Part of the scion trunk was thus saved from injury, and sprouts therefrom were grown into new tops much more quickly and with much less expense than by any other method. Banking with earth has now become a common practice, in Florida and Texas especially, for protecting young trees and nursery budlings. Sometimes, especially with Satsumas, the nursery trees are headed low so that the banking can be extended to cover the trunk and the crotches of the head branches.

## THE FREEZE OF 1913 IN CALIFORNIA

Although minor freezes had occurred in the early days of the citrus industry in California, the freeze of January 5–7, 1913, was so much more severe than any within the memory of men then engaged in citrus culture, and the acreage had by then been so greatly expanded, that growers were confronted with a grave problem. The loss caused by the freeze was a stunning blow. Obviously, continuance in the citrus business required better protection against frost hazards than had been developed in earlier and less severe periods of cold.

Low temperatures prevailed for three days, the last day being the coldest. San Bernardino, Redlands, Pomona, Monrovia, Porterville, Claremont, and Colton registered absolute minimum temperatures of 18° to 19° F.; Riverside, Pasadena, Azusa, El Cajon, Fresno, and Lemon Cove, 20° to 22° F.;

[1] H. J. Webber, University of California Citrus Experiment Station, Riverside, in a statement supplied to the writer October 29, 1944.

Bakersfield, Ojai Valley, and Escondido, 13° to 14° F.; Santa Barbara, Los Angeles, and San Diego, 25° to 30° F. The freeze was accompanied by strong winds. The damage was very great because the cold lasted three days.

Following the freeze, a frost-damage survey was organized by the University of California College of Agriculture under the direction of the Citrus Experiment Station at Riverside, and much valuable material was collected through immediate field observations and in following the results and rates of recovery of the trees for several seasons. In 1919 the results of these surveys were published (Webber *et al.*, 1919), and the discussion given here is in large part summarized from that source.

*Frost injury in relation to orchard sites.*—The elevation above sea level did not indicate liability to frost injury during this freeze, since many other weather factors were involved. In southern California, citrus fruits are grown at elevations ranging from sea level to 2,700 feet or more. In some areas, trees at sea level were severely damaged and groves at elevations of 1,400 to 1,500 feet were unharmed. In other areas, the reverse occurred. Comparisons of temperature-elevation relations should not, however, be drawn as between coastal and interior areas. Neighboring localities within either coastal or interior areas are more nearly comparable in all respects.

Local relative elevation is an important element in influencing temperature; it is usually colder at low levels than at higher levels in the same locality during the typical quiet, frosty nights. Ordinarily, orchard locations with good local air drainage, which means slopes with adjoining lower areas into which cold air can drain off, are advantageous. This circumstance was fairly prevalent throughout southern California at the time of the 1913 freeze, even though there was an accompanying strong wind. Frequently, trees in low areas were entirely defoliated while those higher up in the same orchard retained almost all their foliage uninjured.

In some areas, however, the reverse occurred. In the freezes of 1913 and 1937, the very cold north winds came down over the mountains from the northern desert areas and hit the foothill areas and high mesas before dispersing over the more open valley floor, upsetting the normal trend of local air currents, and many of the orchards on the higher mesas next to the mountains were more seriously injured than those at lower levels. (See for further discussion chap. iv above.)

The freeze of 1913 convinced California citrus growers that more had to be done in the way of orchard heating. Little information was available, however, about effective equipment, and growers had to start with almost no fundamental knowledge of the principles involved. The results of the series of equipment surveys and studies conducted following the freeze were published by the California Experiment Station (Webber *et al.*, 1919).

*Treatments used on injured trees.*—Injuries on the trunk and limbs of frozen trees usually appeared as splits in the bark, and injured patches of bark commonly appeared in the crotches of limbs especially. On young trees, longitudinal splits commonly occurred in the bark on the trunks. Within about two weeks after the freeze, the injured parts of the bark began to dry

out and on the edges of splits to curl outward away from the stem wood. Finally, in the natural process of tree recovery, the dead bark became clearly delimited and could be cut away and the injured areas treated.

Many growers sought to preserve injured bark where splits occurred on trunks and limbs by binding it down with string or tape wrapped spirally around the trunks. Where the wrappings were put on promptly after the freeze, leaving spaces of about an inch between the spirals to allow free access of air, and without wax coverings, observations in general indicated that for vigorous young trees some slight benefit was obtained. Some of the injured areas had also been painted over with grafting wax or asphalt emulsion, and the combined wrapping and painting, which prevented the escape of moisture, apparently stimulated fermentation and increased the injury. In many orchards, also, growers merely painted over many injured areas on the trunks and large limbs with various preparations such as grafting wax, beeswax, asphalt paint or emulsion, or white lead, but it could not be determined that these treatments had increased the healing rate. (Webber *et al.*, pp. 284–286).[1]

*Whitewashing to prevent sunburn.*—Following the freeze of 1913, a rather large number of the defoliated trees in various parts of the State were whitewashed, after the leaves had fallen, to protect them against possible injury by sunburning. Most of the trees, however, were left without such protection. It was found that when the whitewash was put on before new growth had started, the appearance of the new growth was delayed about three weeks. When applications were made after the growth had started, the tender new growth was frequently injured. In general it seemed to be apparent that defoliated trees that were not treated recovered as well or better than those that were treated (Webber *et al.*, 1919, p. 289).

*Pruning frost-injured trees.*—Various methods of pruning were tried. Severe cutting back was widely resorted to; and some that was more moderate, since many growers felt that some sort of pruning should be done at once. Meanwhile, fortunately, many growers hesitated, waiting to make up their minds how to proceed. Thus some orchards went unpruned until new growth developed, which was the certain index of what the tree could do for itself.

The California College of Agriculture ran a special "frost train" soon after the freeze of 1913, making stops throughout the citrus areas of the State and advising growers that it would be better to delay pruning, whenever the frost damage had been at all severe, until the full extent of the damage could be clearly recognized. A few months after the freeze, the experience of orchardists demonstrated the principle of "the less pruning, the quicker the recovery." This was in harmony with the advice given by the College of Agriculture. It was soon found that no one could judge immediately after the freeze just how much of the damaged wood could be expected

[1] It should be noted here that after the dead bark on injured parts is dried out and has been removed, covering the areas with a good asphalt paint or emulsion deters decay and discourages the entrance of borers before the growing bark seals over the wound.

Fig. 286. Badly injured Eureka lemon tree, pruned February 1, 1913, and photographed four and one-half months later, showing the dying back of large limbs after the first pruning. From California Agricultural Experiment Station Bulletin 304, fig. 14.

Fig. 287. Badly injured Eureka lemon tree, unpruned, five and one-half months after freeze, showing the extent of damage and the new growth that has developed. From California Agricultural Experiment Station Bulletin 304, fig. 13.

to recover enough to produce, ultimately, healthy leaves and twigs. It was desirable to permit as much leaf and twig growth as possible on the injured trees, as an aid to their rapid recovery. A lemon tree which was pruned soon after the freeze of 1913 is shown in figure 286; all the seriously injured wood was thought to have been cut out. This was apparently a misjudgment, since, subsequent to pruning, some of the ends of upper stubs of branches died back further toward the trunk. An adjoining tree which was left unpruned for five to six months after the freeze is shown in figure 287. After this tree is pruned to remove dead wood, it apparently will have an appreciably larger amount of healthy twig growth than the tree shown in figure 286, which was considered comparable immediately after the freeze.

A striking example of the effects of different pruning treatments after the freeze was seen in one orchard of old lemon trees that were badly injured. In most of the orchard all wood judged to be badly injured was cut out in February, about a month after the injury. One check row, however, was left which was not pruned until the following summer. These latter trees made the best recovery. The wood on the pruned trees ultimately died back, in most places, beyond the pruning cuts made in February, thus making a second pruning necessary.

In summarizing treatments (Webber and Milliken, 1919), advice was given to let the trees alone for four to six months after a freeze in order to produce the greatest possible leaf area, and then remove the dead wood at one pruning instead of two, as was required with trees illustrated in figure 284.

An experiment was carried on by the California Citrus Experiment Station in a seven-year-old lemon orchard. Four treatments were followed. The pruning was done in March, 1913, two months after the freeze. (Webber *et al.*, 1919, p. 287.)

In treatment 1, the trees were left unpruned. In treatment 2, the trees were pruned moderately, the limbs being cut back only as far as they were thought to be severely injured. In treatment 3, the trees were cut back to the principal branches, without reference to injury, thus being very severely pruned. In treatment 4, the trees were cut off below the crown branches, thus leaving only the trunks. In May, 1914, fourteen months after pruning, the trees of treatments 1 and 2 had developed the largest tops and the most fruit, there being no fruit on trees of treatments 3 and 4. The growth on the trees of treatment 1 after pruning seemed as a whole to be more vigorous and more fruitful than any other. That on trees of treatment 2 was nearly as good, but required a second heavy pruning, which greatly increased the expense. When observations were made in May, 1914, there was no fruit on trees of treatments 3 and 4, and the top development was far behind that of 1 and 2.

The results of these experiments were in accord with those of many growers all over the State. It was stated specifically (Webber *et al.*, 1919, p. 288; Webber and Milliken, 1919) that the best policy to follow in promoting the recovery of injured trees is to delay pruning for four to six months or longer, until the trees have had time to throw out vigorous new growth and plainly

delimit the dead parts. Then all pruning can be done at one time at the least expense, and full fruiting is most rapidly restored. Sunburn also is mostly avoided, because of the protection afforded by the dead branches and the greatest possible number of new leaves; and this greatly lessens the amount of whitewashing, where that is thought desirable.

Injured nursery stock, pruned early, started new growth later than unpruned stock, the time difference sometimes being as much as three weeks.


Fig. 288. Growth of lemon tree which had been sawed off 4 inches above the bud union soon after the freeze of January, 1922. It represents the total growth about 6 inches long from the only adventitious bud, 6 months after the freeze. (Photographed July 21, 1922.)

It was also found that usually it is not worth while to remove frozen fruit from the trees except as it has value for by-products. The danger of spreading fungus spores from the mummied fruit is not sufficient to warrant the expense of removing it.

## THE FREEZE OF 1922 IN CALIFORNIA

The freeze of 1922 in California occurred January 19–22, when minimum temperatures of 18° to 20° F. were registered in many orchards. The weather during the preceding part of the winter had been mild and unusually free from even light frosts; hence the trees had not become so thoroughly dormant as in usual winters. The trees were thus more seriously injured than they would normally have been at these temperatures (Young, 1924).

Prior to this freeze, a good deal of heating equipment had been installed in southern California orchards. Many orchards, however, were not so

equipped, others were inadequately equipped, and oil-storage facilities were limited. Consequently there was heavy damage.

Immediately after this freeze, the Agricultural Extension Service of the University of California made a study of all existing literature on the subject, and conducted also a survey[1] of the citrus-producing counties, in order to learn about all possible methods of treatment that had been used following previous seasons with low temperatures.

Fig. 289. Unpruned tree, thirteen months after the freeze of 1922. Injury was similar to that of trees shown in fig. 287. (Photographed March 9, 1923, thirteen months after the freeze.)

*Pruning and rebuilding injured trees.*—The survey recorded many methods of treatment, and many degrees of cutting back injured wood, besides the removal of dead wood, but there was one practice that was outstanding. Orange and lemon trees that had not been pruned at all for a year or more following the previous freeze had made the most rapid growth and returned to normal production of fruit the earliest. The survey thus checked exactly with the previous conclusions (Webber *et al.*, 1919).

Accordingly, plots were laid out in March, 1922, by the Agricultural Extension Service in several counties. In San Bernardino County, the plots, including both orange and lemon, were designed particularly to demonstrate the results indicated in the survey with respect to the degree of pruning

[1] Under the direction of W. R. Schoonover, Citrus Extension Specialist.

desirable, namely, no pruning, moderate pruning, and severely cutting back. It was believed that these three methods would demonstrate adequately good and bad types of practice adaptable for most orchards. Thus definite records were established, not only of degree of injury, but also of rates of recovery. The lemon plots were in a ten-acre Eureka lemon orchard in Upland; the orange plots, in Cucamonga. The lemon trees at the time of the freeze were nine years old.

Fig. 290. Less severe injury on a nine-year-old tree in the same orchard. Photographed after it had been pruned May 24, 1922, to remove all injured wood. Compare with fig. 292.

In all citrus-growing districts, there was much confusion of ideas with respect to the best treatment for frost-injured trees. Acting on the advice of a man who had seen trees cut back to the ground following the freeze of 1913, the owner of this lemon grove had employed him a short time after the freeze to cut back his most severely injured trees, particularly those with the most bark-splitting on the trunks. Fortunately, a farm advisor observing injured groves drove past this one when the employee had just started work and had sawed off only a few trees a few inches above the ground. The owner was at once consulted, and immediately ordered the work discontinued. The accompanying illustrations, with brief descriptions, tell concisely and strikingly the story of experiments conducted in this orchard.

The tree in figure 288, which had been sawed off four inches above the bud

union soon after the freeze of January, 1922, showed no growth for three months after the freeze, but illustrates the total amount of growth from an only adventitious bud five months after being cut back.

The tree in figure 289 had a degree of injury similar to that in figure 288, but was left entirely unpruned. The photograph was taken March 9, 1923, thirteen months after the freeze.

The tree in figure 290 shows a medium degree of injury, and was pruned

Fig. 291. Recovery of lemon tree shown in figure 290 by September 15, 1922, about eight months after the freeze and nearly four months after pruning.

back accordingly on May 24, 1922 (about four months after the freeze), and so had a well-spaced framework from which new growth could start at once. Figure 291 shows its degree of recovery by September 15, 1922, and figure 292, its recovery by February 17, 1923, about thirteen months after the freeze. This tree began to bear in 1923, and had produced by February, 1924, 106 fruits, and by July, 1924, 173 fruits.

Figure 293 shows a companion tree to that in figure 290, with which it should be compared. It was not pruned during 1922. Note its recovery in figure 294, a photograph taken September 15, 1922, and later in figure 295, a photograph taken February 17, 1923, or twelve months following the freeze. This tree began to bear in 1923, and by February, 1924, had produced 225 fruits or more than twice as many as the tree shown in figure 292 at the

same date. By July, 1924, it had produced 451 fruits or 2.6 times as many as the tree in figures 290, 291, and 292, which had been cut back sooner after the freeze, even though it had been pruned only moderately.

Figure 296 shows a lemon tree badly frozen in January, 1922. It was not pruned until June, 1923. The growth was much better distributed than in trees pruned in 1922, and less wood will have to be removed. Figure 297 shows the same tree after pruning in June, 1923. This is a good illustration of the

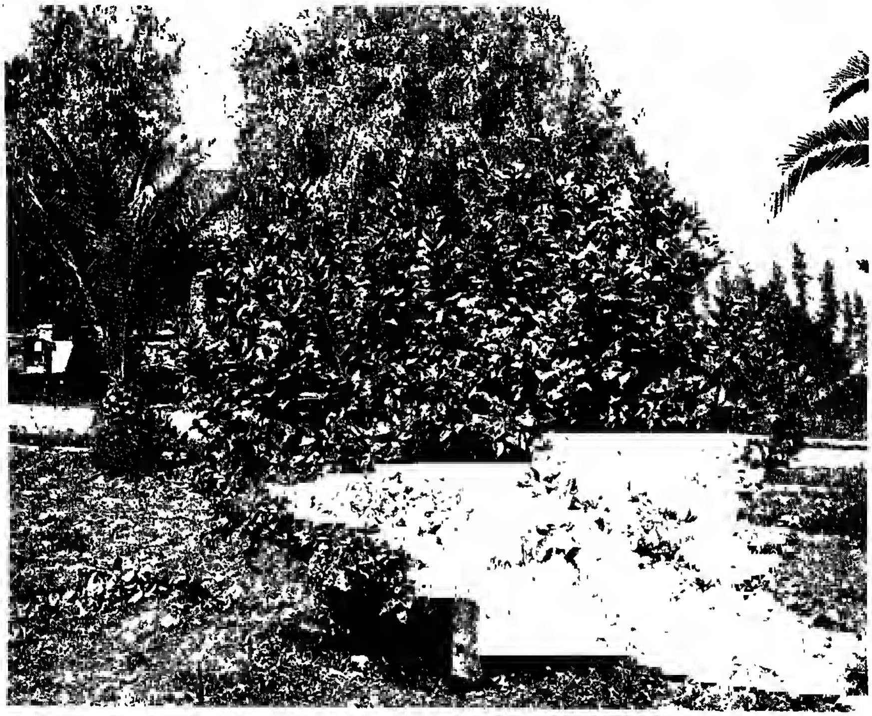

Fig. 292. Recovery of lemon tree shown in figures 290 and 291 by February 17, 1923. This tree began to bear in 1923, and had produced by February, 1924, 106 fruits, and by July, 1924, 173 fruits.

type of wood that should be removed, and of the distribution of the resulting fruit-bearing wood. The principle involved is that many twigs and branches, even though badly injured, will still produce leaves, and that the rate of tree recovery is proportional to total leaf area, regardless of a moderate amount of bark splitting. It is only *dead* wood that does not throw out new leaves and young twigs rapidly, and much of the twig area that appears worthless just after the freeze will develop new growth with startling rapidity if let alone. Accordingly, the "let alone" program for at least a full year following the injury will hasten recovery most. True, the removal of dead wood in a mass of new growth twelve months after the freeze is somewhat difficult

and a mean job, especially with lemon trees, but if fruit production is the criterion of judgment, then it is the proper course, and well worth doing. Distance to cut back cannot be determined until some time after the freeze, and if pruning is done early it always involves a later pruning which greatly increases expenses and actually delays recovery.

It is exceedingly difficult, and consequently more expensive, to try to prune in the next autumn, only some six or eight months after the damage, because

Fig. 293. Companion tree to that shown in figure 290. Not pruned, 1922.

it is then almost impossible to avoid breaking off some of the angular water sprouts which have been quickly produced and always carry a relatively large leaf area. By a year, or perhaps a somewhat longer time, after a freeze the succulent growth will have hardened and rounded, and much less breakage will occur; also, the new growth will have so developed that attention can be given to reshaping, or otherwise planning the future development of the tree.

This description thus far applies to lemon trees because they are more susceptible to frost injury than orange or grapefruit trees. The methods of treatment are equally applicable, however, to orange and grapefruit trees, as has been observed from contemporary experience.

After every freeze there is always a question of what should be done about

very young injured trees, or of promoting the recovery of injured trees that are only one to three years old. Trial plots on this problem were started in the spring of 1922 in San Bernardino County. They demonstrated that, for lemon trees even as young as three years, no pruning for twelve months is the advisable course to follow. It was also demonstrated that the injured trees have far more value than replanted trees. Following such a policy is also important in saving the expense of the replanting.

Fig. 294. Same tree as that shown in figure 293. Recovery by September 15, 1922.

Subsequent to the freeze of 1922 it was demonstrated conclusively, on pruning plots of frost-injured trees in San Bernardino County, that the strong fall growth the first season, even though later frozen back, is far better than growth lacking in vigor. Such vigorous growth always has a beneficial effect on the tree. Withholding water to check growth, because of the possibility that damage might later be done by frost, proved inadvisable. This conclusion applied to trees of all ages, and particularly to mature groves that had been allowed to run down and become devitalized.

In the course of a survey following the cold weather of November, 1931, it was found that in the coast counties (Blanchard, 1932) it had been more difficult to rebuild young lemon trees than young orange trees. It was also observed that a much greater degree of success had been attained in rebuilding young trees, beginning with 1922, in the interior counties of California

than in the coast counties. The much drier atmosphere of the former was doubtless the reason: high, dry temperatures had acted as adequate disinfectants before any special treatments were applied to prevent decay. There is evidence to indicate (Blanchard, 1932) that in the coastal sections the young trees are more susceptible to fungi that cause wood decay than are similar trees in the interior districts; also, that various heavy dressings, such as grafting wax, when applied before the wounds had thoroughly dried,

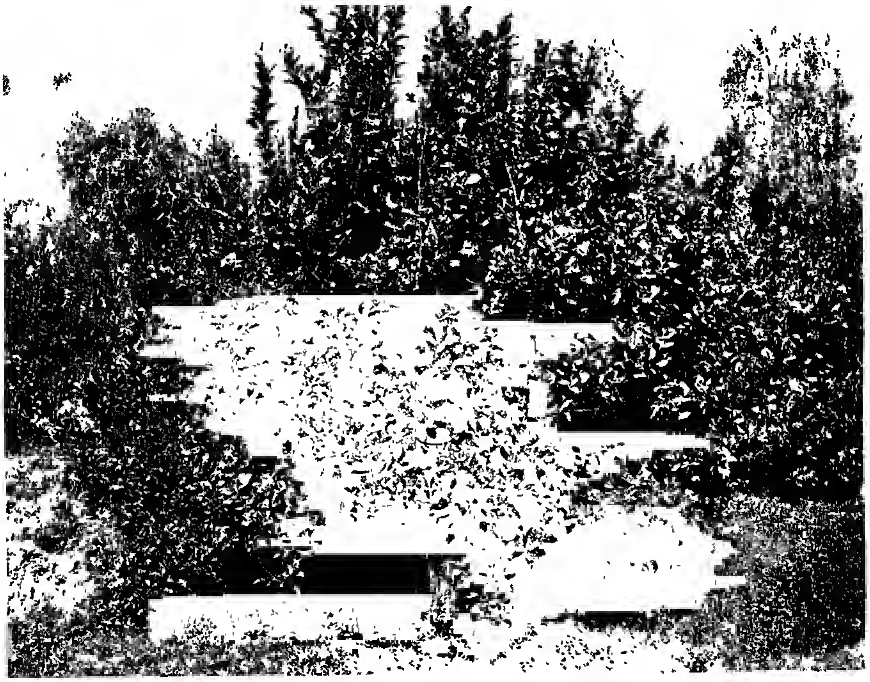

Fig. 295. Same tree as that shown in fig. 293. Recovery by February 17, 1923. This tree began to bear in 1923, and produced by February, 1924, 225 fruits, and by July, 1924, 451 fruits.

favored the activity of injurious parasitic and saprophytic organisms. It appears obvious that if the application of wound dressings had been deferred in the coastal counties for a few more weeks, until higher temperatures had dried the wounds thoroughly before the various dressings were applied, results might have been much better. However, permanganate of potash could have been applied safely at any time, because its high degree of liquidity permits rapid drying.

*Rebuilding young trees.*—From the evidence available, it appears that in the interior counties it certainly pays to rebuild both young lemon and young orange trees unless they are very badly injured: there is an actual saving of time in bringing them into bearing, as compared with the rate of growth and

ultimate production of newly planted nursery trees; and the scarcity and high price of nursery trees following a major freeze make a replanting operation two or three times as expensive as normally.

The recommendations of Blanchard (1937, p. 184) respecting the pruning methods to be used in rebuilding young trees, when the proper time comes,

Fig. 296. Badly frozen lemon tree, Tulare County, California. This tree was not pruned until June, 1923. Growth is distributed better than in trees pruned in 1922, and less wood will have to be removed.

are probably the most reliable now available, particularly for the coast counties, and are thus given here. They are mainly based on the recovery of trees in experimental plots in Los Angeles County after the freeze of 1922. Five different degrees of injury are considered, as follows:

1. Where the injury is confined to the outer shell of foliage—

The general recommendation offered for the treatment of trees in this class is no

pruning during the season following the freeze, with the exception of the removal or control of suckers or rank growing water sprouts. . . . The main object should be to maintain all the leaf surface possible as a means of bringing the trees back into balance at an early period. The first pruning a year after the freeze should be light or moderate and confined to removal of dead wood and thinning out where the foliage is too dense.

Fig. 297. Same tree as that shown in figure 296, after pruning. Note type of wood removed.

2. Where a considerable part of the top is killed and frost cracks occur on the main scaffold limbs—

Trees injured to this extent require rebuilding of the framework system. They should not be given any pruning treatment until several months have elapsed. . . . Where the injury has been quite severe, it appears best to do no pruning at all the first season. In some cases, however, the formation of a new framework system may be encouraged and the distribution of the framework branches controlled to some

extent by a moderate pruning during the summer. The worst injured framework branches should be cut back to a point below all serious frost cracks. If possible, such cuts should be made to smaller lateral branches in order to check the vigor of the growth of the new shoots which will appear and which will serve as new leaders . . . *All exposed branches should be whitewashed to prevent injury from sunburn.*

This treatment will result in the production of various shoots some of which will serve as new leaders. These should not be pruned until the following spring, at which time they should be thinned, removing all those poorly placed and leaving as many as are needed, usually from four to six, as main leaders. These should not be headed in or "stubbed" as this will prevent the production of fruiting laterals. If the leaders grow too long, after laterals have formed, they may be shortened in, cutting to a side branch.

Where the trees are not pruned at all the first season following the freeze, the pruning treatment the second season is essentially the same as that just described, with the exception that the new vigorous shoots will perhaps not be as well distributed. Care will be required in the proper selection of those to be left for the future framework branches.

3. Where the top is partially or completely killed to or just below the head of the tree but the trunk still remains sound—

Delay cutting back until mid-summer to definitely determine the degree of injury. Trees affected to this degree will require rebuilding by establishing a new head. The entire top of the tree should be removed, cutting below all large frost cracks. New vigorous shoots will be produced which must be carefully thinned in order to provide for the formation of a satisfactory framework. . . . More shoots should be allowed to grow the first year or two than will eventually be desirable. When the tree has made a satisfactory new head, surplus branches may be removed.

4. Where the top is killed or badly injured and the injury extends down the trunk but not to the bud union—

Trees in this condition will require rebuilding from a new shoot produced from a point above the bud union. The recommended treatment is to cut off the head of the tree after it is definitely determined. . . . that the top is killed, leaving the trunk as a support for the shoot from which the tree is to be remade. A well placed shoot should be selected and tied to the trunk in order to give it an upright position. A number of other shoots should be left to serve as nurse limbs for the first year or two. The selection of the shoot from which the future tree is to be made should preferably not be made until mid-summer. If the nurse branches appear to compete with the main shoot, they should be suppressed by pinching back part way. When the new shoot reaches a height of 38 to 40 inches, it should be topped at from 28 to 32 inches to force the development of a head. . . . The nurse branches should be left for at least the first season with small trees and for two years with larger trees. . . . After having served their period of usefulness, these shoots should be removed, cutting close to the trunk, and the old stump cut off on an angle of forty-five degrees close to the base of the new trunk. After drying out for a few days, the wound should be disinfected and after drying again, sealed with a good wound dressing such as asphalt paint or grafting wax. Emulsified asphalt may be used before drying out, provided it is preceded with mercuric cyanide disinfectant. There is nothing to be gained by applying such a paint in the early stages of frost injury.

5. Where the injury extends to the bud union—

Trees injured to this extent must be rebuilt from below the bud union. The most satisfactory method appears to be that in which a strong growing shoot is forced

**out [from the rootstock] and the tree treated in the same general manner as that described in class four. In the fall of the season following the freeze this shoot may be large enough for dormant budding. [The budding of this shoot and the formation of the new head would be the same as in the production of a nursery budling; see this volume, chap. i.]**

Data on the San Bernardino plots following the freeze of 1922, and continued through 1926, showed, however, that in the interior districts, at least, no growth should be removed for the first full year. In midsummer, after the growth is well started, leaders may be selected, the terminal buds from the other growth being pinched off so that a maximum leaf area is maintained without competition for height between the other growth and the leaders selected for the main branches. Where the top is killed but the trunk is uninjured, sprouts will often start from buds near the top of the trunk which can serve as frame branches. If the young tree is killed down to the bud, a sprout coming from below the bud can be trained for a new trunk by tying it to the old dead trunk for support and then budding the live sprout later in the summer. Such trees may develop much faster than a replant, but with trees one to three years old replacement appears to be better.

On the nine-year-old trees in the San Bernardino plots in 1922 all bark-split limbs healed very rapidly where no pruning was done the first year. thereby permitting the tree to throw out the maximum number of leaves, which restored the normal functioning of the tree in the shortest possible time. Limbs and twigs healed thus quickly acquire strength to sustain heavy crops of fruit as rapidly as they return to normal production. Any degree of cutting defers such restoration.

On the other hand, where the splitting is so extensive that the bark rolls back for one-fourth to one-third the circumference of the limb or trunk, careful follow-up work is required. The peeled bark is of no use in rebuilding (see Webber *et al.*, 1919, p. 283), since all new bark comes from the edges of the wound and grows toward the center of the frozen area until it is closed.

Many growers have thought that the loose separated bark should be left for protection from sunburn. Since it serves as a harbor for insect pests, and sometimes defers drying too long after spring rains, even in the orchards of the interior counties, its early partial removal to the degree that light may penetrate to the healing edges is desirable. In the coast counties, the development of Sclerotinia, molds, etc., is even more pronounced.

After a freeze, foliage will develop early enough, if no pruning is done, to provide adequate shade in most seasons. Where it does not do so, the wounds should be painted with asphalt base paint. No painting should be done, however, until all the wounds have dried thoroughly, and in the coast counties it should be done at times when there is no fog. Blanchard (1937, p. 184) wrote, "An additional cause for the greater percentage of failures in the coastal section is believed to have been the prevailing practice of sealing up all frost cracks and wounds by means of wound dressings without permitting them to dry out, thus favoring the activity of injurious parasitic and saprophytic organisms [fungi causing wood decay]."

## THE FREEZE OF 1937 IN CALIFORNIA

In January, 1937, occurred the most severe freeze, or freezes, that southern California has ever experienced. Young stated (1939, p. 317): "Considering both temperature and duration, the 1937 freezes broke all known records in all California citrus districts except those in the Sacramento Valley. All of January was cold but the two principal cold periods occurred between January 7–11 and January 19–27, the freeze of the latter period in general being the more severe. The full effect of the first freeze had not become fully evident before the second freeze came. The minimum temperatures recorded in most sections ranged between 15° and 20° F. and in the Imperial and Coachella valleys temperatures of 12° and 13° F. were reached."

Because large numbers of orchard heaters were used, the damage to trees and fruit was in general much less than in the freezes of 1913 or 1922. Nevertheless, many orange and lemon groves were insufficiently protected, or entirely unprotected, and the trees suffered severely; many were entirely defoliated, and the small twigs and limbs were seriously injured or killed. Injuries frequently extended to fairly large limbs, measuring three to four inches in diameter, and many young trees were killed below the bud unions.

*Pruning and rebuilding frozen trees.*—After this freeze, the information on the pruning and rebuilding of frozen trees that had been gained from the observations and experiments following the freezes of 1913 and 1922 was available and was widely publicized. Growers in general understood and followed the best approved methods. Observations on the results obtained served to confirm fully the correctness of the conclusions reached earlier (see "The Freeze of 1922 in California," above).

*Effect of freeze on citrus grown under dates.*—Since the freeze of 1922, the practice of planting citrus as a combination crop in date gardens had become common, and several hundred acres of such plantings of grapefruits, oranges, and tangerines, ranging in age from one to nine years, were available for study following the freeze of 1937. It was a general observation that these citrus plantings were much less severely injured than citrus orchards planted alone and they commonly survived the exceptional temperature of 12° to 13° F. without losing their leaves.

*Whitewashing frozen trees to prevent sunburn.*—After every freeze that is severe enough to result in serious defoliation and twig injury, it is commonly recommended that the trees be whitewashed to prevent sunburning. Webber (1937*b*, p. 185) has questioned whether this is good practice, in view of the very general observation that most orchards are not whitewashed, yet apparently recover as well as those that are whitewashed, or even better.

Sunburning is supposed to be caused by the greater solar heat and the greater intensity of the actinic or ultraviolet rays to which the tissues are suddenly exposed when the leaves fall. It is well known that if the trunk or large limbs of a citrus tree are exposed to direct sunlight in summer by sudden removal of the leaves, serious sunburning is likely to occur. Freezes that kill and remove the leaves, however, almost invariably occur in winter, when

the solar radiation and the intensity of actinic rays are only about one-half what they are in summer (Webber, 1937). Freezes, furthermore, usually occur at times when the soil is abundantly moist, the humidity high, and the temperatures moderate. Under these conditions, the partial shade protection afforded by the frozen twigs and limbs is likely to suffice against sunburn, without whitewashing.

*Fertilizing and irrigating frozen trees.*—Often, when trees have been injured by freezing, fertilization and irrigation have been increased to hasten their recovery. Observations made after every major freeze have indicated that this is an error, since the trees with reduced foliage are not in a condition to utilize the excess applications, which may actually be harmful. Apparently, fertilizer applications to frost-injured citrus trees should be reduced so as to correspond with the reduction in total leaf area, and then be gradually increased to normal as the tops increase in size. The same rule applies to irrigation. Most growers overirrigate frost-injured trees, and thus cause damage to the feeder-root systems. This applies to all soils, but the risk is greater in orchards on the soils most retentive of moisture.

## SUMMARY OF PRUNING TREATMENTS

The results of all plot tests on the recovery of frozen trees in California indicate: (1) that no dead wood should be removed, nor live wood pruned, until the second spring or summer after the freeze, but that, among the new sprouts developed, leaders to form the new top should be selected by midsummer of the first year and the other new-growth branches should be disbudded; (2) that, the second season, most of the dead wood should be removed and the secondary growth thinned, particularly to leave space for the leaders, some of their laterals being disbudded to effect proper spacing; and (3) that, the third year, any remaining dead wood should be removed and the new growth thinned to effect a good distribution of fruit-bearing wood. Frequent follow-up attention of this kind makes heavy pruning unnecessary at any time, and restores maximum production at the earliest possible date.

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